S.V. TARASOV

TECHNOLOGY OF WATCH PRODUCTION

TRANSLATED FROM RUSSIAN

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S. V. TARASOV

TECHNOLOGY OF WATCH PRODUCTION

(Tekhnologiya chasovogo proizvodstva)

Approved by the Administration of Educational Institutions of the Ministry for Automation and Instrument-Making of the U.S.S.R. as a Textbook for Technical Colleges

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ANNOTATION

This book describes the methods used in the mass production of pocket- and wristwatch parts and reflects the experience acquired by the Soviet watch industry.

The book is intended for students of technical colleges specializing in watch manufacture. It may also be of aid to factory workers and to engineering personnel employed in processing small high-precision parts.

FOREWORD

The watch industry created during the Five-Year Plan periods has arrived at a new stage in its development. New plants are going into production, and existing ones are being reconstructed. The staff of factory workers and engineering personnel is being enlarged, and training programs are being introduced on a large scale. The training of new personnel is hampered, however, by the lack of literature dealing with the technology of watch manufacture.

It is the purpose of the present book to fill this gap. The basic manufacturing processes used in making pocket- and wristwatches are described, as are the special machines, devices, stamping and cutting tools, etc. The book presents information on the metals used in the manufacture of watch parts and discusses the fundamentals of manufacturing-process design. The engineering processes are in some cases illustrated by sample operations as carried out in the manufacture of alarm-clock parts.

The material presented corresponds to the watchmaking section of the syllabus of the course on "Manufacture of Precision Instruments and Tools" for technical schools. In the author's opinion the manufacture of jewel bearings constitutes a separate subject, and is therefore not treated in this book. Since heat treatment is included in the program of the special course for technical schools, the author has confined himself to mentioning hardening, tempering, cementation and aging.

Due to limitations of space, the book cannot treat thoroughly all the problems encountered in the manufacture of pocket- and wristwatches.

The author will be thankful for any suggestions and for criticism of the book's contents. These should be addressed to the author, c/o Publisher: Moskva, 1, Tret'yakovskii proezd, Mashgiz.

INTRODUCTION

In watch manufacture, as in other branches of instrument and tool manufacture, use is made of cold stamping, turning on automatic and semiautomatic lathes, milling, gear hobbing, drilling, thread-cutting, heat-treating, grinding, polishing, and similar processes, as well as of auxiliary processes, such as electroplating, lacquer-coating, etc.

However, for any given component, the manufacturing processes used in pocket- and wristwatch-making are frequently quite different from those which would be used in tool and instrument manufacture for the preparation of similar parts.

The characteristic features of watch manufacture result from the very *small dimensions* of the processed parts, and from the *high precision* and *excellent surface-finish quality* required.

Many dimensions of watch parts are below 1 mm, and some nominal dimensions may read 0.018, 0.08, or 0.15 mm.

The gear moduli are very small – 0.05 mm in some cases, and the gear ratio of a pair may be as high as 10, making it necessary to use gear pinions having between 6 and 12 teeth of a modified cycloidal shape.

Tolerances on some dimensions of basic parts are as close as 0.01 to 0.02 mm. Tolerances for journal diameters, bearing bores, and center distances may come to 0.005 mm.

The requirements for trueness, parallelism, concentricity and other form and position parameters of the parts are very strict.

The requirements for accuracy of gear-tooth shape are also very severe, in order to minimize friction losses in the transmission of power from the mainspring to the escapement.

The small dimensions of the parts and their narrow tolerances render their measurement by conventional limit gages difficult. Accordingly, universal measuring devices are used in watch manufacture such as micrometers, dial gages, etc., as well as special measuring devices equipped with micrometers and dial gages. Geometric shapes and many linear and angular dimensions are often measured on optical and mechanical-optical instruments such as optical comparators, microscopes, etc.

The solution to the problem of interchangeability is thus seen to be more difficult in the mass production of watches than in other branches of instrument and tool manufacture.

Watch mechanisms, parts and assemblies must be interchangeable not only by their dimensions but also by their physical properties, such as the constant period of oscillation of the escapement.

The high quality of surface finish is required mainly to minimize power losses in friction pairs and meshing gears. The external appearance of the watch is also a function of the finish of certain of the parts. Good surfaces on steel parts also increase their corrosion resistance.

In the production of pocket- and wristwatches many hardened steel parts are finished to $\nabla\nabla\nabla\nabla$ 12 – $\nabla\nabla\nabla\nabla$ 13. Nonhardened steel parts and parts made from nonferrous alloys generally have surface finishes of $\nabla\nabla\nabla$ 8 – $\nabla\nabla\nabla\nabla$ 10 and above.

It will be seen from the description of watch-manufacturing processes which follows that the application of the usual metalworking techniques to the production of watch parts having small dimensions and low mechanical strength, and demanding high dimensional and form accuracy as well as superior surface finish, is characterized by the use of more accurate special machines, different processing conditions, devices, stamping and cutting tools of special design, and special engineering methods.

Watch production differs from other kinds of instrument manufacture in the extensive use which is made of nonferrous alloys supplied according to engineering specifications (see Chapter II), and in the relatively high proportion of wages in the total production costs resulting from the relatively small volume of materials used and the large amount of labor invested.

The high unit price of the materials notwithstanding, the share of wages in the total costs involved in the production of a wristwatch is about three times as large as that of the materials used up.

Lastly, watch production is characterized by the considerable amount of manual work involved, mainly in assembly operations.

Chapter I

FUNDAMENTALS OF TECHNOLOGY

BASIC CONCEPTS AND DEFINITIONS

Production and Technological Processes

The *production process* of a plant or shop is the totality of operations which transform the initial materials and blanks which enter the plant into finished products.

A *technological process* is a part of the production process which is directly connected with the alteration of the shape, properties or state of the material.

The technological process is subdivided as follows*.

An *operation* is a part of the technological process which is executed on a definite component (or group of several components processed simultaneously) by one factory worker (or a definite group of factory workers) continuously and at the same workplace. A time and work-expenditure rate is established for the operation.

A *pass* is a part of an operation which is executed on a surface (or several surfaces) by one or several simultaneously operating tools under given processing conditions.

A change in any of the above-mentioned factors – the tool, the processed surface or the processing conditions, the others remaining unchanged – constitutes a new pass.

A *step* is that part of the pass (or the operation) which results in the actual removal of a layer of material from a given surface by a given tool.

A *hold* is that part of an operation which is performed in one chucking of the processed component (or of several simultaneously processed components) and is performed at a station.

A *position* is meant to indicate each of the several spatial relationships between the processed component and the tool or the machine in the same chucking.

Setting up is that part of the operation which is concerned with the preparation of the machine for the execution of the various passes (bringing up of the tool, starting the machine, etc.). Setup times are taken into account when establishing the rates for the operation.

The technological process for each product is entered in detail on engineering charts which are the basic documentation necessary for applying the production process.

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* Established by the Committee for Technology of VNITOMASh.

"Technological discipline" consists in the faithful carrying out of all instructions appearing in the engineering charts, and constitutes one of the main conditions for the manufacture of high-quality products.

Watchmaking plants make use of several different kinds of technical documentation, for different purposes.

The degree to which the technological process is provided with technical documentation, and the thoroughness of the documentation, depends on the type of production.

Types of Production

Depending on the output volume and the character of production organization, one distinguishes between: unit production, series production and mass production.

Eache of the above types covers a range of situations, and intermediate cases occur. Thus, depending upon the number of types of products which are produced and on the quantity of products in a production series, series production can be large-series or small-series. Mass production can be organized as flow-line mass production.

Unit production involves the manufacture of single products or of small batches of products (several pieces), with large time intervals between successive runs. Universal equipment and devices and general-purpose tools are used, permitting the processing of parts of various dimensions and diverse configurations.

Personnel engaged in unit production must have high qualification, because of the diversity in the operation they must perform.

In this type of production the details of the technological processes are not worked out in advance. The general sequence of operations is prescribed for most parts, and only for particularly complex parts are the processes worked out in more detail.

Costs are high and production is slow under unit-production conditions.

Series production involves the manufacture in batches of several products which alternate periodically. One or several operations are carried out at each workplace, and either the entire batch of parts passes from operation to operation together, or it is divided into groups.

Small-series production is characteristic of plants producing various products in small batches.

The equipment used in small-series production is mainly universal but special devices and specialized cutting tools and measuring instruments are also used to a limited extent. The processes for small-series production are worked out in detail, and norms and rates are fixed.

Operations are associated with available equipment of a particular type, or even with a particular machine.

Large-series production is characterized by the same basic features as those which characterize small-series production, but considerable differences exist between the two types of production.

The diversity in the parts manufactured is smaller in large-series production. The series are much larger and the product designs are more stable in time. Special devices, cutting tools and measuring instruments are used liberally, and this investment in tools is usually economically justified. Production costs are lowered, and the production-time cycle shortened in large-series production as compared with small-series production.

Mass production is the steady production of uniform products. The elements of work have a narrowly specialized character, and a specific operation is assigned to each workplace.

Wide use is made in mass production of specialized and automatic machinery, special cutting tools and measuring instruments, and a variety of automatic and mechanized instruments and devices.

The large investments involved in the preparations for mass production make it essential that the product design, the technological process, and the equipment design be worked out carefully and thoroughly.

Because the same operation is constantly repeated at a given workplace, and because special equipment is widely used, the personnel quickly master the operation entrusted to them and achieve a high rate of productivity. Production costs are lower in mass production than in any other type of production process.

The large investment necessary for the preparation of mass production is justified economically by the increased output and the lower production costs.

Because only one operation is performed on each machine, setup time is saved and it is possible to achieve higher rates of equipment utilization than in other types of production.

If the workplaces (machines) are arranged in accordance with the sequence of operations, the part will pass directly from workplace to workplace and emerge completely processed after the final operation.

In order that this flow be possible, all operations must take the same amount of time. In practice, however, the time required by the various operations is usually not the same for all of them and both technical and organizational measures are taken with the aim of equalizing the time required by the different operations: improvement of the design of clamping devices in order to reduce the loading time, introduction of multiple-chucking devices, etc. In particular cases certain operations may be conducted in parallel at several workplaces.

A mass production process in which the work is conducted along a flow line is called flow-line production.

The most important problem in flow-line production is the synchronization of operations, to ensure that all operations require the same time or a multiple of it. The number of product units or parts coming off the conveyor per unit of time serves as an index of the flow-line productivity.

Plant Structure

Each plant is divided into shops, each of which has a given class of equipment, and workers and engineering personnel having specialized in similar fields.

The following are some of the types of shops: stamping, automatic machines, mechanical coating, (electroplating, lacquer-coating), heat treatment, assembly, etc.

The shops in which parts are produced and assembled are called **basic shops**.

Plants making pocket- and wristwatches have the following basic shops: preparatory shop, stamping shop, automatics shop, plate-and-bridge shop, case shop* (cases, dials and hands), escapement shop (sometimes called "movement" shop), mechanical shop (gears, barrel parts and pallet levers), coating shop (electroplating), heat-treatment shop, and assembly shop.

The entire process of watch manufacture, beginning with the raw material and ending with the finished product, takes place within the basic shops.

In addition to the basic shops, each plant has **auxiliary shops** which provide production services.

Some examples of auxiliary shops are the tool shop, the mechanical-maintenance shop, the power shop, and the construction-maintenance shop.

The plant management comprises the following departments for production control:

1. The production-dispatching department plans the work schedules of the production shops and supervises the fulfillment of the plant's production program. The manager of the production-dispatching department is the production manager and all the basic shops of the plant are under him.
2. The chief-production engineer's department is charged with designing the technological processes and supervising their application in production. This department establishes the technical norms and rates for the processes, designs the production equipment, and sets consumption standards for the basic and auxiliary materials.
3. The chief-designer's department is charged with designing the products to be manufactured by the plant (in this case – watches).

A watch laboratory is attached to this department for the purpose of testing both watches produced by the plant and prototypes of new designs to be introduced into production.

4. The technical-supply department supplies the plant with all basic and auxiliary materials.
5. The chief-mechanic's department is charged with machinery maintenance and with keeping the buildings, installations and power system of the plant in working condition.
6. The technical-control department is responsible for the compliance with technical instructions in the shops, tests the materials received by the plant and inspects the finished products.

MACHINING ACCURACY

Machining accuracy is of utmost importance in instrument-making technology and is especially important in watch manufacture.

Processing accuracy is understood to refer to the degree to which the finished parts correspond to the form and dimensions specified by the drawing.

Variations in the dimensions of parts produced can result from many factors which influence the manufacturing process. Inaccuracy in the

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* The plate-and-bridge shop and the case shop are combined in some watch plants into one plate-and-case shop.

machine or cutting tools, tool wear, inhomogeneity of the material being processed, and deformations in the machine, the tool or the part during processing, are a few of these factors.

Errors

In the process of machining all parts of the machine, the tool and the blank are subjected to cutting forces which cause deformations. In drilling deep holes the drill is deflected from the desired hole axis; in turning shafts or axles between centers on a lathe the axles bend, etc.

Deviations in the dimensions and the form of the parts being made are due to causes such as those described above; these deviations are usually called errors and are classified as being of the systematic or of the random type.

An error is called s y s t e m a t i c if it is constant for all the parts of a given batch or if it changes in a regular manner within the batch.

Thus, if holes are drilled using a drill which is 0.2 mm larger than it should be, all the holes will be larger by 0.2 mm than if they had been drilled with the correct drill. This will be a systematic error. Another example of systematic error is that resulting from the wear of the cutter, which leads to a progressive increase in an external diameter or a progressive decrease in an internal diameter of a machined part.

An error is called r a n d o m if it has different values for different parts within the same batch and is not subject to any apparent law. Holes drilled by the same drill will have various dimensions, due to various factors of random origin.

The systematic errors are determined by analytic-calculation methods and the random errors are determined statistically. A formula is known which establishes the relationship between the various elements of the system machine – tool – part and can be used for the analytical method.

However, this method is inconvenient because lengthy computations are necessary for each factor. For example, 72 factors are known to affect hobbing.

It is difficult to determine the combined influence of several simultaneously operating factors or primary errors using analytic-calculation methods. Calculation methods are, for these reasons, being widely supplemented by statistical methods of investigation. According to the statistical methods, the totality of many phenomena is treated rather than individual phenomena or factors. The process of investigation is split into two stages– collection of experimental data, and its processing using the methods of mathematical statistics and the theory of probability. We will illustrate the application of this method by a concrete example. Let us assume that a batch of 100 parts has been manufactured according to an established technological process.

If the dimension in question ($d = 10$ mm) is measured in a batch of parts processed under uniform conditions, we will obtain different values of the dimension in the different parts, varying between a maximum of $10^{+0.014} = 10.014$ mm and a minimum of $10_{-0.012} = 9.988$ mm.

The difference between the maximum and minimum diameters, called the **range**, will be equal to

$$\varphi_{act} = d_{max} - d_{min} = 10.014 - 9.988 = 0.026 \text{ mm} = 26\,\mu.$$

The diameter of each of the parts in the batch is measured and the results are arranged in a table.

To that end the range is split into several equal class intervals, say, of 2 μ each and the number of parts whose measured diameter lies within the limits of each interval is recorded (Table 1).

TABLE 1

Results of the measurement of a batch of parts

Class intervals of actual diameter (d_i) in increasing order, mm		Deviation from the nominal diameter $\delta_i = d_i - d_{nom}$, in μ		Frequency
from	to	from	to	m_i
9.988	9.990	−12	−10	1
9.990	9.992	−10	−8	3
9.992	9.994	−8	−6	5
9.994	9.996	−6	−4	9
9.996	9.998	−4	−2	13
9.998	10.000	−2	0	20
10.000	10.002	0	+2	14
10.002	10.004	+2	+4	12
10.004	10.006	+4	+6	9
10.006	10.008	+6	+8	7
10.008	10.010	+8	+10	4
10.010	10.012	+10	+12	2
10.012	10.014	+12	+14	1
				$\sum m_i = 100$

The **frequency** of a given interval is the number of parts whose diameter lies within the limits of the given class interval.

A graph of the frequency m_i as a function of the deviation δ_i can now be plotted (Figure 1). The points are connected by straight lines; and the broken line obtained characterizes the scatter of dimensions in the batch of parts investigated and is called the **actual distribution curve or the distribution polygon.**

If the number of parts and class intervals is increased indefinitely, the interval width becomes infinitely small, and in the limit the distribution polygon is transformed from a broken line into a continuous curve.

This curve is called the **theoretical distribution curve** and it can be expressed analytically in the form

$$y = \varphi(x),$$

where x = the value of the random magnitude;

$\varphi(x)$ = the value of the ordinate of the continuous distribution curve.

The distribution function $\varphi(x)$ of a variate x is called the **distribution law.**

It has been established by numerous investigations that under production conditions, where the equipment operates automatically and there is no dominating factor among the sources of error, the scatter of errors in a batch of parts conforms to or closely approaches the law of normal distribution. This law is expressed analytically by the equation

$$y=\frac{1}{\sigma\sqrt{2\pi}}e^{\frac{-(x_i-x_{av})^2}{2\sigma^2}}=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{\delta^2}{2\sigma^2}},$$

where y = frequency of appearance of an error of given absolute value;

x_{av} = arithmetic mean of the actual dimensions (population mean):

$$x_{av}=\frac{x_1+x_2+\ldots+x_n}{n}=\sum_1^n\frac{x_i}{n};$$

x_i = actual dimensions;

δ = the variable error;

σ = standard deviation, determined from one of the following expressions:

$$\sigma=\sqrt{\frac{(x_1-x_{av})^2+(x_2-x_{av})^2+\ldots+(x_n-x_{av})^2}{n}}=\sqrt{\frac{\sum_1^n(x_i-x_{av})^2}{n}}$$

or

$$\sigma=\sqrt{\frac{\delta_1^2+\delta_2^2+\ldots+\delta_n^2}{n}}=\sqrt{\frac{\sum_1^n\delta_i^2}{n}}.$$

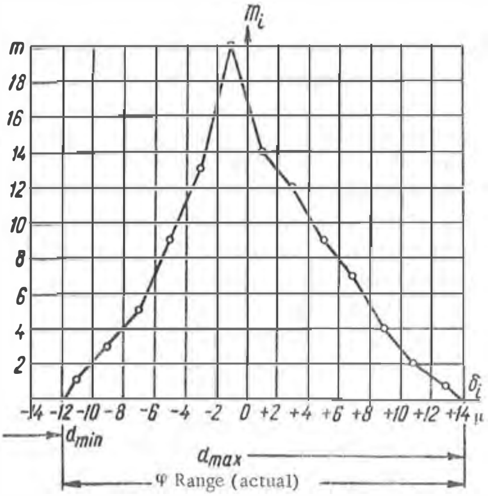


FIGURE 1. Distribution polygon

The curve representing the law of normal distribution is given in Figure 2.

The axis of symmetry of the curve is determined by x_{av}, which is called the population mean.

The standard deviation σ is the second main parameter of the law of normal distribution.

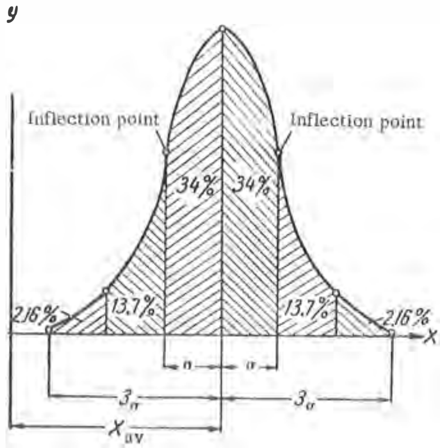


FIGURE 2. Curve of normal distribution

The larger the standard deviation, the broader and less steep the curve. A small value of σ, on the contrary, will cause the curve to be narrow and steep.

We present for comparison, in Figure 3, three curves having different values of σ. A small value of σ indicates small random errors, and a high processing accuracy. The value of σ can therefore serve as a criterium of process accuracy.

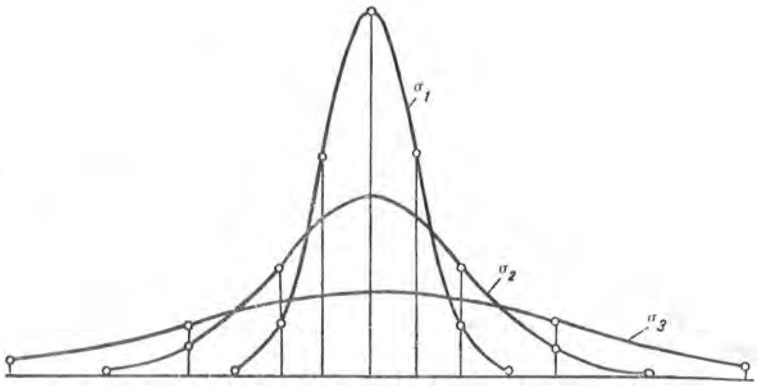


FIGURE 3. Normal distribution curves with various values of σ

The normal distribution curve has two inflection points, situated symmetrically on both sides of x_{av} at $\pm\sigma$.

The standard deviation $\pm\sigma$ separates the region of frequently met errors from that of rarely met errors.

The branches of the normal distribution curve continue to infinity in both directions and approach the X-axis asymptotically. The area under the curve limited by the ordinates $\pm 3\sigma$ includes 99.7% of all the cases and therefore, normal distribution curves are limited in practice to $\pm 3\sigma$; this giving an error of less than 0.3% (Figure 2).

The accuracy with which the standard deviation can be determined depends on the number of parts measured.

For practical purposes it is wholly sufficient to determine the standard deviation σ with an error of $\pm 10\%$, and in order to determine σ to this degree of accuracy it is sufficient to measure 50 parts.

Investigation of the Accuracy of Technological Processes on the Basis of the Distribution Curve (Statistical Method)

Using the statistical method, the manufacturing accuracy of a given process (the resultant error caused by the interaction of several primary errors) can be obtained, but the separate influence of each of these errors cannot be directly observed.

The influence of a given factor can be determined by comparing distribution curves. If the distribution curve for the dimensions of a batch of parts conforms to the law of normal distribution, the probability that the error relative to the mean value in a part will not be larger than $\pm x_0$ (the shaded area of Figure 4) will be

$$\frac{1}{\sigma\cdot\sqrt{2\pi}}\int\limits_{x_{av}-x_0}^{x_{av}+x_0} e^{\frac{-(x_i-x_{av})^2}{2\sigma^2}}\,dx.$$

Instead of calculating the value of the integral corresponding to the specified value of x_0 in each instance, the table in Appendix I can be used.

In this table the total area under the curve is taken as unity. The value of $z=\frac{x_0}{\sigma}$ is given in the first column, and the values of the integral, designated by $\Phi(z)$, are listed in the following columns. The values of z appear in the first column to the first decimal place; the second decimal place appears at the head of the following columns. Thus, for $z = 2.48$; $\Phi(z) = 0.9868$; for $x_0 = 3\sigma$; $\Phi(z) = 0.9973$ or 99.73%.

If the probability is given, the value of z can be determined from the formula $z=\frac{x_0}{\sigma}$ and therefore the limiting deviation from the mean value can be calculated.

Thus, given a 1.5% reject rate in a batch of parts, we obtain the value $z = 2.43$ from the table for $\Phi(z) = 0.985$.

Taking $\sigma = 0.02$ mm, we will determine deviation x_0 from the mean value x_{av}.

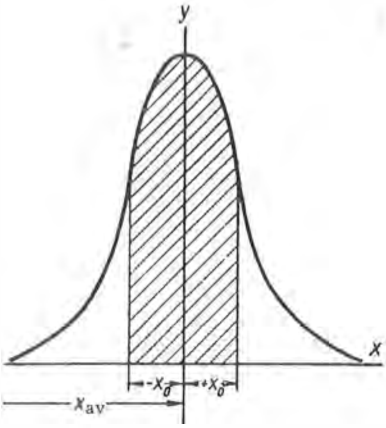


FIGURE 4. Normal distribution curve

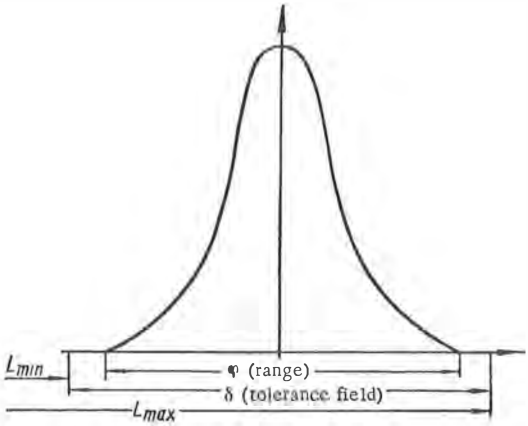


FIGURE 5. Range and tolerance field

$x_0 = z \cdot \sigma = 2.43 \times 0.02 = 0.0486$. The total tolerance is $0.0486 \times 2 \approx 0.10$ mm. Allowing a 1.5% reject rate and for $\sigma = 0.02$ mm, the tolerance can be established as 0.10 mm. For the same value of σ, and allowing a 0.27% reject rate, the tolerance must be $6\sigma = 0.12$ mm.

With the aid of distribution curves one can characterize the process accuracy not only with respect to dimensional errors, but also with respect to deviations from the correct geometrical shape.

The accuracy of the technological process is determined by the basic condition that the range must not exceed the tolerance field (specification limits).

If the condition is fulfilled, the work will be conducted within the limits of the established tolerance, and therefore without rejects. This condition is presented graphically in Figure 5.

Since the range is 6σ, production without rejects is defined by the following inequality:

$$6\sigma < \delta.$$

If this inequality is not fulfilled and $6\sigma > \delta$, it is necessary to replan the engineering process or to envisage supplementary processing of those parts which fall outside the tolerance field.

We will consider several examples.

Example 1. Parts from two batches, produced by the same technological process but at different machine settings are measured.

The distribution curves plotted for the two batches will be roughly identical, but will be displaced from one another by the value a (Figure 6).

When working with holding and locating fixtures, the shift can be explained only by a difference in the positions of the working parts of the machine, the clamping devices and tools for the two cases.

If we plot a curve for a mixed batch of parts, processed by different reamers, different punches, etc., the curve will have two summits (Figure 7).

The multiple-summit curve can be considered as the summation of curves having different arithmetic means (population means).

If the various groups of parts are machined by different processes, the individual distribution curves, which together form the common multiple-summit distribution curve, may also differ in shape.

Example 2. Assume that a batch of parts manufactured by an invariable process using locating fixtures has been measured. The distribution curve is plotted and superimposed on the tolerance field. The range is seen to be smaller in absolute value than the tolerance field (Figure 8), but since the population means is displaced to the right, rejects will result.

The proportion of rejects (as a percentage of the total number of parts in the batch) is represented by the hatched area of the curve.

The following conclusions can be drawn on the basis of the curve obtained.

The process adopted can reliably produce work without rejects, since

$$\xi = 6\sigma < \delta.$$

The fact that rejects are obtained is due to the shift of the population mean relative to the tolerance field.

In order to produce work without rejects, all that is necessary is to readjust the machines.

Example 3. It is required to select from among three possible technological processes the one ensuring maximum accuracy.

Three groups of parts are experimentally machined using the three processes, and after measuring the parts the standard deviation for each group is calculated.

The process which gives the smallest value for σ will be ensuring the highest accuracy.

Having investigated a process by means of distribution curves, conclusions can be drawn concerning its accuracy under given processing conditions. On the basis of these data, specifications for the accuracy of the various technological processes can be established.

Using these specifications, engineers can correctly select the process giving the required accuracy.

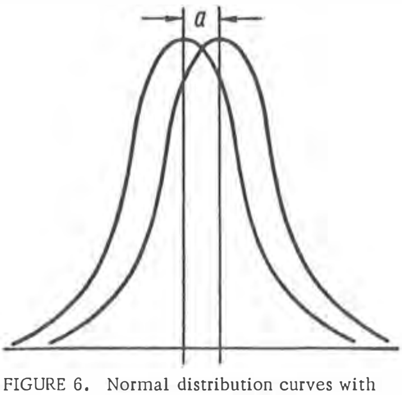


FIGURE 6. Normal distribution curves with different positions of the population mean

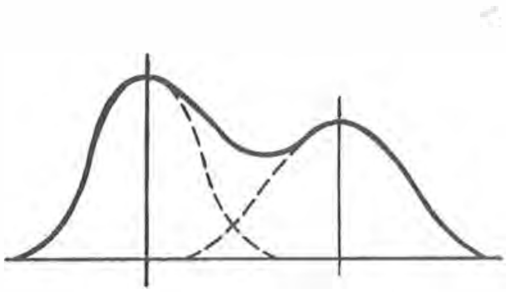


FIGURE 7. Two-summit distribution curve

The influence of individual factors on the process accuracy can be investigated with the aid of the distribution curves. The factor in question is varied, keeping the remaining parameters of the process unchanged. The comparison of the distribution curves obtained before and after the variation indicates that the method of determination of process accuracy by means of distribution curves is of general applicability and makes it possible to find methods for increasing process accuracy.

The basic methods for increasing the machining accuracy in watch production are:

1. Increasing the durability of the tool, thus achieving increased stability in the machined dimensions.

2. Reducing the range of the variation in the mechanical properties of the metal used.

3. Machining the important surfaces of the part in one hold.

4. Combining the design and reference surfaces and using one single surface as a base for the various operations.

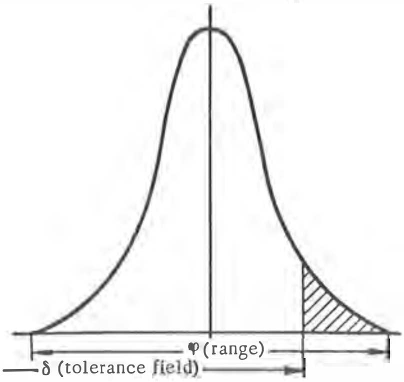


FIGURE 8. Distribution curve for work produced by improperly adjusted machine

Average economic accuracy. Each machining process has a definite accuracy under normal production conditions. On the basis of numerous observations, the accuracy of the various machining processes has been established and is called the *average economic accuracy*.

The average economic accuracy is the accuracy achievable under normal production conditions, that is, when the machines have the specified accuracy, the fixtures and tools correspond to the drawings and specifications, the work is carried out as specified, and the personnel have the required qualifications.

Data on the average economic accuracy in watch manufacturing are given in Table 2.

TABLE 2*

Average economic process accuracy in watch manufacturing

Process	Average economic process accuracy, mm
Turning on Swiss-type automatic screw machines	
a) bar diameter up to 6 mm:	
for diameter	0.005—0.010
for length	0.010—0.020
b) diameter from 6 to 10 mm:	
for diameter	0.010—0.020
for length	0.020—0.030
c) diameter from 10 to 16 mm:	
for diameter	0.015—0.025
for length	0.030—0.050

* Based on data from watch plants.

TABLE 2 (cont'd)

Process	Average economic process accuracy, mm
Facing and counterboring flat watch parts on the S-57M, S-81A, S-175, S-178 machines, etc.:	
for diameter	0.020—0.050
for depth	0.010—0.030
Milling gears and pinions on the S-40 and 530A machines, on the the external diameter:	
module 0.15 mm	0.010—0.025
" 0.15 to 0.30 mm	0.015—0.035
" 0.30 to 0.50 mm	0.030—0.050
Milling recesses in flat brass parts on the S-50, S-187, S-210 machines, etc.:	
for depth— area up to 50 mm^2	0.010—0.025
for depth— area more than 50 mm^2	0.020—0.030
for contour	0.020—0.050
Drilling holes:	
diameter up to 1 mm	0.008—0.015
diameter from 1 to 3 mm	0.015—0.030
Reaming holes:	
diameter up to 1 mm	0.005—0.010
diameter from 1 to 3 mm	0.008—0.015
Shaving holes:	
diameter up to 3 mm	0.005—0.010
diameter from 3 to 7 mm	0.010—0.020
Stamping	
Blanking:	
a) blanks of size up to 25 mm and thickness up to 2 mm	0.020—0.050
b) blanks of size larger than 25 mm and thickness more than 2 mm	0.050—0.150
Shaving	
a) parts of size up to 25 mm and thickness up to 2 mm	0.010—0.020
b) parts of size larger than 25 mm and thickness more than 2 mm	0.020—0.050
Combined blanking and shaving:	
a) parts of size up to 25 mm and thickness up to 2 mm	0.015—0.030
b) parts of size larger than 25 mm and thickness more than 2 mm	0.030—0.100
Rolling and drawing	0.010—0.050
Cylindrical grinding:	
diameter up to 1 mm	0.010—0.015
diameter from 1 to 3 mm	0.015—0.020
diameter from 3 to 10 mm	0.020—0.025
Surface grinding (thickness):	
area up to 5 mm^2	0.010—0.020
area from 5 to 50 mm^2	0.020—0.030
area more than 50 mm^2	0.030—0.050
Circular polishing:	
diameter up to 1 mm	0.005—0.010
diameter from 1 to 3 mm	0.010—0.015
diameter from 3 to 10 mm	0.015—0.020
Plane polishing:	
area up to 5 mm^2	0.020—0.030
area from 5 to 50 mm^2	0.030—0.050

Parts which are to be processed on a machine must be positioned relative to the cutting tools and must then be held in position by clamping devices.

Selection of the reference surfaces during the part-design stage determines how the part will be dimensioned. Depending upon the reference surfaces selected, a means for positioning and fastening the parts for machining is adopted, and this in turn determines the basic design of the clamping device.

The reference surfaces also determine the position of the part in the assembled product and its interconnection with the other parts.

Thus, the concept of "reference surface" denotes the totality of surfaces, lines or points in relation to which are orientated those surfaces which adjoin (in the finished product) other components or those surfaces of a component which are machined at the given stage of manufacturing of said components.

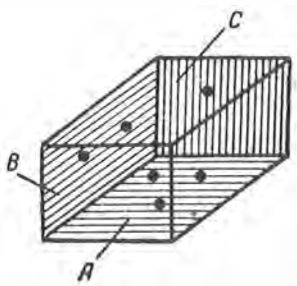


FIGURE 9. Reference surfaces on a prismatic part:

A–main reference; B–guide; C–stop surfaces.

We distinguish between main reference surfaces, guide surfaces, and stop surfaces.

The position of these surfaces in a prismatic part is shown in Figure 9.

In order to direct (orientate) the part on the main reference surface we have to set it on three points which determine the position of the plane.

After the part is set on the main reference surface, its orientation along the guide surface is determined by two points.

The part having been set along the main and guide surfaces, one point suffices to fix it with respect to the stop surface. If orientation of a part in three directions is not necessary during assembly or machining, the number of reference surfaces reduces to two or one.

Let it be required to machine the upper surface and maintain the dimension a on the part shown in Figure 10, a.

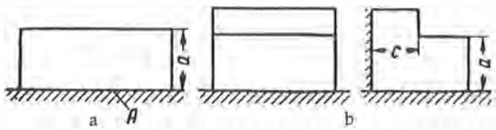


FIGURE 10. Machining parts according to different holding surfaces

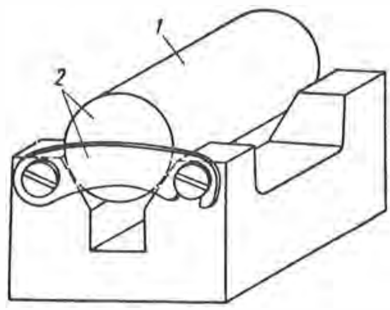


FIGURE 11. Reference surfaces of a cylindrical part:

1–double guide surface; 2–stop surface.

In this case the part to be machined is set on the main reference surface A, while the guide and stop surfaces are of no special importance.

If, on the other hand, we are required to machine the dimensions a and c (Figure 10, b), we set the part along the main and the guide reference surfaces, the stop surface being of no special importance.

In these examples the concept of "reference surface" includes one or two surfaces of the part, respectively.

The position of cylindrical parts, such as rollers or shafts, is determined by the position of the axis of the external cylindrical surface in the horizontal and vertical directions, and by the position of an end surface.

It is sufficient to support cylindrical parts on four points of the external cylindrical surface and on the end, as shown in Figure 11.

A cylindrical surface along which the part is set as in Figure 11 is called a d o u b l e g u i d e s u r f a c e.

T h e s t o p s u r f a c e in this case is the cylinder end.

Let it be required to turn a shoulder on a cylindrical blank (Figure 12). When the blank is clamped, the cylindrical surface of the collet serves simultaneously as main reference, guide and stop surface for obtaining the dimension $2.5^{-0.02}$ mm. The cylindrical surface of the collet also serves as the guide surface for obtaining the dimension $8.5^{-0.10}$, while the internal shoulder of the collet serves as both the main reference surface and the stop surface.

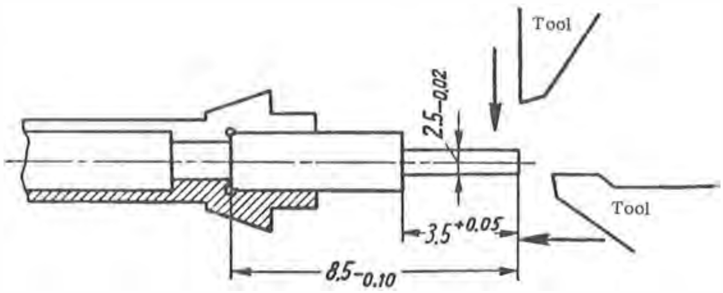


FIGURE 12. A cylindrical part held in a collet

Surfaces are classified, according to their function, as being either d e s i g n, a s s e m b l y, h o l d i n g o r m e a s u r i n g s u r f a c e s.

T h e d e s i g n s u r f a c e s of the part are the totality of surfaces, lines or points relative to which the other parts of the product are orientated in the designer's calculations.

A n a s s e m b l y s u r f a c e is the totality of surfaces, lines or points relative to which the other parts of the product are actually orientated.

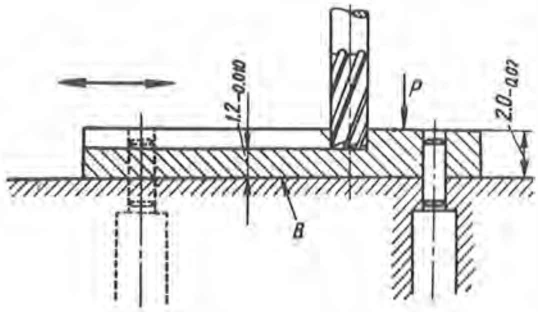
A h o l d i n g (t e c h n o l o g i c a l) s u r f a c e is the totality of surfaces, lines or points relative to which a surface being machined is orientated during the manufacture of the part.

A m e a s u r i n g s u r f a c e is that surface (or set of surfaces) from which the dimensions are measured.

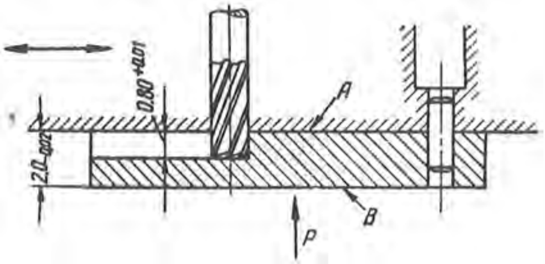
Parts processed on machines are set and held in universal or special clamping (fastening) devices.

Since all the parts of a type are located on the same surface in the same manner, and are machined identically, their dimensions will be identical within the process accuracy.

When working with locating fixtures, l o c a t i n g   e r r o r s appear in addition to the random errors described earlier.



a



b

FIGURE 13. Locating error for different holding surfaces

The following example will serve to illustrate how the selection of the holding surface influences the machining accuracy and the design of the fixtures.

Example. It is required that the dimension $1.2_{-0.010}$ be held in machining the watch plate shown in Figure 13, a. This is achieved directly by means of the setup shown in Figure 13, a, where the dimension $1.2_{-0.010}$ is measured from the holding plane B. The variation in the dimension 1.2 in the parts will depend only on random factors causing scatter in the dimensions.

In Figure 13, b, it is required to hold the dimension $0.80^{+0.01}$, measured not from the holding plane B, but from the plane A.

If the part is set on plane B, the dimension 0.8 will depend both on random factors and on the actual magnitude of the dimension 2 mm which has been machined previously. In this case the dimension 0.8 will have deviations of a magnitude of $0.01 + 0.02 = 0.03$ mm. In order to increase the accuracy, the tolerance for the dimension 2.0 mm would have to be narrowed. This, however, would render the machining more complex and costly.

The best solution in the given case is to set the part on plane A.

This example shows that, all other conditions being equal, the highest accuracy is achieved when the plane from which the dimension in question is measured is the holding surface, that is when the m e a s u r i n g and the h o l d i n g s u r f a c e s coincide.

Technological processes are accordingly preferably designed so that the reference and design surfaces coincide. It is also desirable to use the same surface for as many operations as possible. The transition from one surface to another is always bound up with supplementary errors. The selection of the holding surfaces must not only ensure the required machining accuracy, but must also allow the reliable fastening of the part in the fixture.

The calculation of the locating error as a function of the locating method for different cases is given in the specialized literature.

ALLOWANCES AND INTEROPERATIONAL TOLERANCES

The metal layer which must be removed in an operation or suboperation in order to obtain the specified dimension is called the *allowance for the given operation or pass.*

The value of the allowances specified depends both on the method used to make the premachined blanks and on the machining process in question. The more accurate the blank, the smaller the machining allowance required. Larger allowances are allowed for roughing operations than for finishing operations.

The question of the magnitude of machining allowances is of great technical and economical importance because the metal removed by machining is as good as lost, since the value of shavings is much smaller than that of the original metal stock.

In addition, the removal of an excessively large allowance requires time, thus lowering the productivity and the capacity of the equipment, and raising tool-wear and power-expenditure rates.

Excessively large allowances are thus seen to reduce the economic effectiveness of the process.

Excessively small allowances are not desirable either, since they make the setting and adjustment of the parts on the machines more difficult and require higher accuracy in the blanking operations, increasing their cost.

Machining allowances specified must therefore be as small as is possible under the given process conditions.

Long production experience has made it possible to fix average allowances for blanks obtained by various methods or being prepared for various machining processes and these can be found in the handbooks or factory specifications, or can be calculated.

The allowances for machining external and internal cylindrical surfaces are given on the diameter (for both sides). The allowances on external planes and end surfaces are given for one side; and their numerical values are accordingly half as large as those for corresponding cylindrical surfaces.

The total allowance for the machining of a surface is the sum of the allowances for all the various operations.

In order to ensure that one operation will not remove the minimum allowance intended for the next operation, *operational tolerances* are set on the nominal value of the allowance for each operation, and thus the maximum and minimum values for each operational allowance are fixed.

The operational tolerance on the last operation is the tolerance on the final dimension for the machined surface. The scheme of disposition of the operational allowances and tolerances is given in Figure 14.

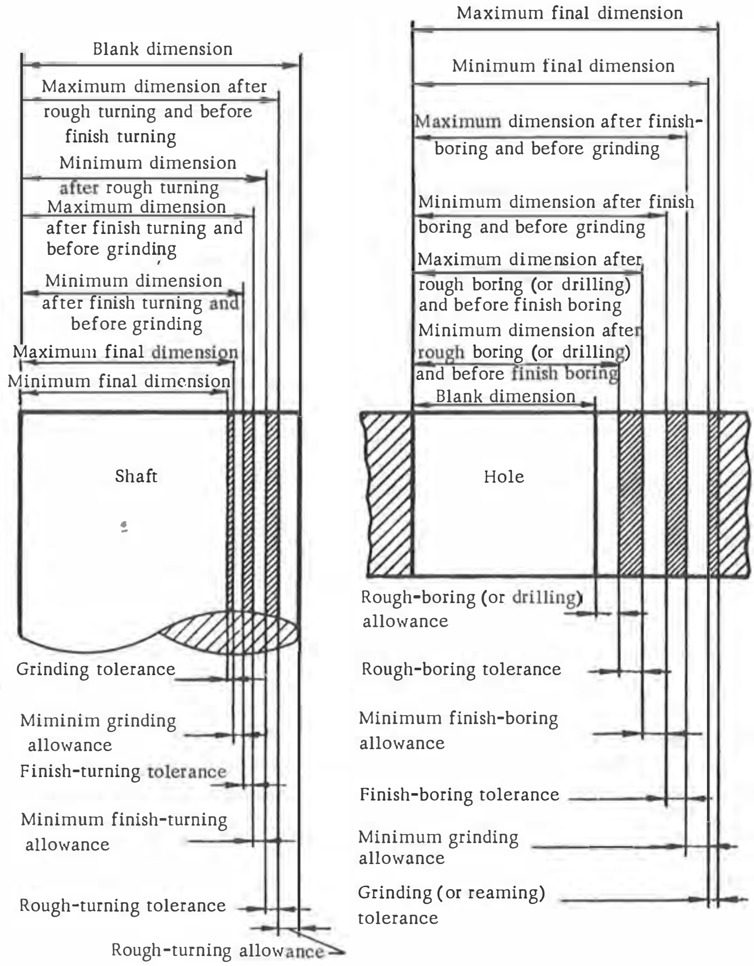


FIGURE 14. Scheme of disposition of the operational allowances and tolerances

In watch production a considerable proportion of the parts have no blank allowances.

SURFACE FINISH

Machining with cutting and abrasive tools always leaves traces of the cutting tool or grinding wheel grit on the machined surfaces. These traces take the form of crests and hollows, imparting roughness to the surfaces.

The rougher the machining, the larger the magnitude of the unevenness on the machined surfaces. Each machining process produces a distinctive surface finish.

In the case of metals, the state of the surface is assessed according to two scales of magnitude. The deviations from the regular geometrical shape, such as the waviness, are called the surface macrogeometry. The degree of roughness and the height of the roughness hills and valleys are part of the surface microgeometry (Figure 15).

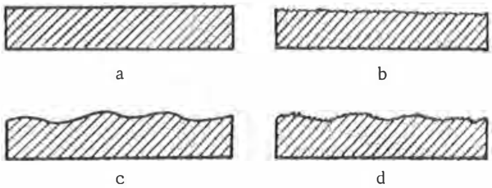


FIGURE 15. Surface macro- and microgeometry:

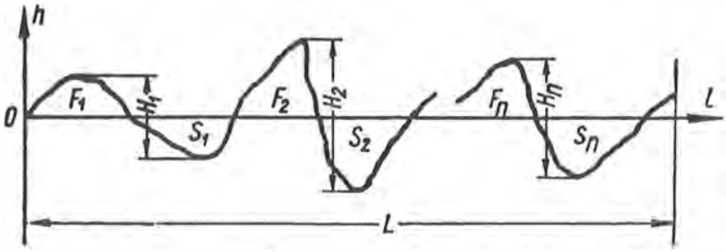
a–flat smooth; b–flat rough; c–wavy smooth; d–wavy rough.

The measure of surface-finish quality is the height of the roughness crests.

After machining operations (such as reaming, grinding, etc.) the roughness crests are of very small height (thousandths of a millimeter) and cannot be seen by the unaided eye. It is customary therefore, in measuring surface finish, to express the roughness in μ.

According to GOST 2789-51, the surface-finish quality must be expressed either by the root mean square [r. m. s.] average deviation of the microroughness crests from the mean ($H_{r.m.s.}$) or by their arithmetic average deviation from the mean (H_{av}).

The r.m.s. averages height of the microroughness crests is defined as the square root of the mean square of the roughness-crest heights measured from the mean line. The mean line is defined as the line dividing the crests and valleys of the profile in such a way that the areas enclosed between the line and the profile contour on both sides of the line are equal (Figure 16).



$$F_1 + F_2 + \ldots + F_n = S_1 + S_2 + \ldots + S_n$$

FIGURE 16. The mean line of the roughness profile

Classification into surface-finish groups and classes, and the symbols used according to GOST 2789-51, are given in Table 3. For classes 1 to 4 the surface roughness is determined according to arithmetic mean deviation from the mean surface; for classes 5 to 12 by the r. m. s. deviation, and for classes 13 – 14 by the arithmetic mean deviation.

TABLE 3

Classification of surface finish according to GOST 2789-51

Surface-finish-quality class	Symbol	Roughness height, μ	
		$H_{r.m.s.}$	H_{av}
1 2 3	▽1 ▽2 ▽3	— — —	From 125 to 200 „ 63 „ 125 „ 40 „ 63
4 5 6	▽▽4 ▽▽5 ▽▽6	— From 3.2 to 6.3 „ 1.6 „ 3.2	From 20 to 40 — —
7 8 9	▽▽▽7 ▽▽▽8 ▽▽▽9	From 0.8 to 1.6 „ 0.4 „ 0.8 „ 0.2 „ 0.4	— — —
10 11 12 13 14	▽▽▽▽10 ▽▽▽▽11 ▽▽▽▽12 ▽▽▽▽13 ▽▽▽▽14	From 0.1 to 0.2 „ 0.05 „ 0.1 „ 0.025 „ 0.05 — —	— — — From 0.06 to 0.12 „ 0.06

By agreement between the parties (producer and customer), it is permitted, according to GOST 2789-51, to assess the surface in classes 5-12 by H_{av} rather than by $H_{r.m.s.}$ according to the relations given in Table 4. The reason for this is that not all enterprises have profilometers reading in $H_{r.m.s.}$ The majority of the existing instruments for measuring surface roughness can measure only the height of the roughness.

TABLE 4

Crest height (H_{av}) and surface-finish classes

Class	5	6	7	8
H_{av}, μ	From 10 to 20	From 6.3 to 10	From 3.2 to 6.3	From 1.6 to 3.2
Class	9	10	11	12
H_{av}, μ	From 0.8 to 1.6	From 0.5 to 0.8	From 0.25 to 0.5	From 0.12 to 0.25

GOST also specifies the division of certain classes into categories, but in practice such a division is necessary only in rare cases, as when two surfaces of the same class are being compared.

Surface-finish quality is of great importance in instrument production, as it directly influences the operational properties of the parts and joints.

It has been established by many investigations that the resistance to wear of parts in moving contact depends to a considerable extent on the surface-finish quality, and that instruments having frictional surfaces with an unsatisfactory finish lose up to 50% of their accuracy in the initial period of use as a result of the rapid wear of these surfaces and the resulting increase in clearances.

It has also been established that the corrosion resistance of parts depends on the quality of their surface finish.

The parts which go into instruments and watches must, therefore, meet high requirements relative to the quality of their finish. Many frictional surfaces in watches are machined to a class 12 or 13 surface-finish quality.

The classes of surface-finish quality attainable by the various processes used in watch manufacture are given in Table 5.

Inspection of surface-finish quality is of great importance in watch production because of the fact that the tolerances on small parts are of the same order of magnitude as the microroughness height. Thus, turned wristwatch pinions, arbors, and shafts have a tolerance on the journal diameter of 0.005 mm, or 2.5 μ per side, while the average microroughness height for a class 8 surface-finish quality is 1.6 to 3.2 μ.

The microroughness range is thus seen to be almost equal to the tolerance field diameter.

In order to ensure that the roughness height is only a fraction of the dimension tolerance, a higher class of surface-finish quality (class 10) must be achieved in turning these parts on automatic lathes.

Inspection of the surface finish of watch parts under production conditions necessitates accurate methods, and efficient and simple-to-handle inspection instruments. Unfortunately, no instruments satisfying these requirements are available to date. The existing instruments are suitable mainly for use under laboratory conditions or, in particular cases, for random sample inspection in the shop.

The existing instruments for the determination of the surface-finish quality either use a *tracer stylus* or are based on the use of *optical phenomena*.

Instruments of the first type feel the inspected surface by means of a diamond or corundum stylus (for small diameters – a thin metal strip) and transmit the amplified vibrations of the stylus (or the strip) to a photographic plate or to the instrument pointer.

Such instruments can measure roughness with a height of from 0.2 to 20 μ and they are therefore suitable for surface-finish qualities between class 12 and class 5. The following are among the instruments using a tracer: a) the KV-4 Kiselev electrodynamic profilometer which measures the surface roughness in $H_{r.m.s.}$ (from 0 to 10 μ) and gives direct scale readings (accuracy roughly ± 5%); b) the Ammon and Levin profilographs IZP-5 and IZP-17 (H_{max} from 0.2 to 250 μ), which record profilograms on a photographic plate (accuracy 10-20%).

The optical instruments are of three types: those based on the method of the oblique light beam, those operating by the interference method, and those operating by the comparative method.

The oblique-beam instruments, such as the double microscope MIS-11, permit the measurement on flat surfaces of roughnesses of the order of 1 to 70 μ corresponding to surface-finish quality between class 3 and class 9. The accuracy of the instrument is 5 – 25%.

TABLE 5

Surface-finish quality attainable by various machining processes used in watch production

Process	Surface-finish-quality class (GOST 2789-51)
Cold stamping	
Contour blanking	▽▽6
Gear blanking	▽▽6– ▽▽▽7
Contour shaving	▽▽▽7– ▽▽▽8 *
Swaging	▽▽▽9– ▽▽▽▽10
Hole shaving	▽▽▽9– ▽▽▽▽10
Turning	
Turning on Swiss-type automatic screw machines:	
a) external surfaces	▽▽▽7– ▽▽▽8
b) shaft and pinion journals	▽▽▽9– ▽▽▽10
Counterboring:	
a) without particular requirements relative to surface quality	▽▽▽7– ▽▽▽8
b) with high requirements relative to surface quality	▽▽▽8– ▽▽▽9
Facing	▽▽▽7– ▽▽▽8
Machining of holes	
Drilling:	
a) prior to internal threading	▽▽6
b) for journals of axes and pinions	▽▽▽7
Reaming	▽▽▽9– ▽▽▽▽10
Milling	
Flat surfaces:	
a) roughing	▽▽6– ▽▽▽7
b) finishing	▽▽▽8– ▽▽▽9
Gear hobbing:	
a) high-module teeth (from 0.2 to 0.5 mm)	▽▽▽7– ▽▽▽8
b) low-module teeth (up to 0.2 mm)	▽▽▽8– ▽▽▽9
Grinding	
Prior to polishing and lapping	▽▽▽8–▽▽▽9
Centerless	▽▽▽9–▽▽▽▽10
Fine and decorative	▽▽▽9–▽▽▽▽10
Cup-wheel grinding	▽▽▽▽10–▽▽▽▽11
Polishing	
Dimensional:	
a) cylindrical surfaces	▽▽▽▽11–▽▽▽▽12**
b) flat surfaces	▽▽▽▽12–▽▽▽▽13
c) profiles	▽▽▽▽11–▽▽▽▽12
Decorative (flat surfaces)	▽▽▽▽11–▽▽▽▽12
Drawing	
Round or profiled bars	▽▽▽9 –▽▽▽▽10

* Special cases ▽▽▽9–▽▽▽▽10.
** Special cases ▽▽▽▽13.

The interference instruments, such as the Linnik microinterferometer, measure roughness height from 0.08 to 1.2 μ corresponding to surfaces between class 9 and 13; the accuracy being 5 to 15 %.

In comparative instruments the processed part and a standard specimen are compared under a microscope. The microscope used for this purpose in watch manufacture is of the NIIChASPROM design.

The method of comparison is more efficient than the other methods and can be used under shop conditions for random sampling.

ECONOMICS OF THE TECHNOLOGICAL PROCESS

Economic Effectiveness of the Design

Any product can be assessed from two points of view: from the point of view of its technical and operational properties, and from the point of view of the economic effectiveness of the design.

The term "economic effectiveness of the design" refers to the technical and economical characteristics of a design from the point of view of its production.

The product of highest economic effectiveness among a group of products having identical technical-operational characteristics will be that which can be produced by the most economical processes.

The economic effectiveness of a design can be assessed by a number of coefficients.

The coefficient of recurrence of parts K_r. If the number of different parts in the product is equal to N_p and the total number of parts is N_t, then

$$K_r = \frac{N_t}{N_p}.$$

The higher K_r, the better the economic effectiveness of the design. In watch production this coefficient varies between 1.2 and 1.6.

Coefficient of design continuity K_a. This coefficient expresses the degree to which parts (N_a in number) adopted from other products produced by the plant, and which can be produced by the available equipment, are used.

$$K_a = \frac{N_a}{N_t - N_{pur}},$$

where N_{pur} = the number of purchased parts;
N_t = the total number of parts.

A high value for K_a reduces the time and the investment involved in the preparations for production and simplifies the design.

Only those parts should be adopted, however, which are not liable to constitute "bottlenecks" in production. Complex parts should not be borrowed if they can be replaced by simpler ones in the new design.

The standardization coefficient K_s, expresses the degree to which standardized parts are used in the design:

$$K_s = \frac{N_s}{N_0 - N_{pur}}.$$

The higher the value of K_s, the smaller the investment in machinery, and the simpler the production design.

The coefficient of metal utilization K_m characterizes the efficiency of material utilization, and is defined as the ratio of the net weight of the parts to the weight of materials used:

$$K_m = \frac{p_{net}}{p_{gross}}.$$

The value of K_m rises with the quality of the machining methods. Its value is low in watch production (K_m = 0.25 to 0.30).

The economic effectiveness of a design can be assessed by many other indexes as well, such as the ratio of the labor required by the machining processes to the total amount of labor required in the manufacture of the product. These indexes are a measure of the excellence of the technological process and the degree to which the most productive processes, such as cold stamping, are used.

A very important index of the economic effectiveness of a design is the amount of labor expended in assembling the product. This index is a function of the degree of interchangeability: the higher the degree of interchangeability, the less fitting work is required, the simpler the assembly, the lower the labor costs involved, and the better the economic effectiveness of the design.

The average accuracy class for a product is also an index of the economic effectiveness of the design. Production is simpler and cheaper and the economic effectiveness better, the lower the average accuracy requirements which will still meet all the technical and operational demands.

In the production of pocket- and wristwatches 35 to 40% of the parts fall into the second class of accuracy, 5 to 10% belong to the first class, and the remainder are in the 3rd and 4th classes.

A correct assessment of the economic effectiveness of a design can be made only on the basis of all the indexes together.

Rate Setting

A time norm must be established for every job (or work in general) required by the technological process.

The time norms are necessary for calculating wages, for determining the output capacity of machines, shops or plants, for calculating the length of the production cycle, for designing the production programs and the necessary equipment, for planning work schedules and determining the economic indexes and for organizing line production on a conveyor.

A time norm is generally established for each operation.

The reciprocal of the time norm is called the output norm and it gives the number of parts to be produced per unit time (such as one work shift). The output norm is defined as the ratio of the duration of the shift [in minutes] to the time norm: $N = 480/T_p$.

In practice two kinds of time norms are in use: experimental-statistical and calculated-analytical (technical). The experimental-statistical norms are established on the basis of the personal experience of the foremen, engineers or rate-setters, or by reference to the norms existing in the industry. Statistical data on the actual rates for similar operations carried out in the past can also serve as a basis for rate setting.

In establishing experimental-statistical norms, no technical calculations are undertaken which would take account of the equipment's output capacity, of progressive cutting techniques,of the strength of the cutting tools, etc.

The experimental-statistical norms therefore reflect the technical level of a past period and do not take into account the technical growth and present-day state of production engineering.

For this reason these norms cannot stimulate the further growth of work productivity and are of no use in a socialist economy.

The calculated-analytical (technical) time norms, on the other hand, are based on the most effective use of all the means of production in the operation to be normed: optimal regimes, use of high-output tools and fixtures, use of the advanced experience of production technicians, etc.

The technical time norm is composed of several elements and is expressed by the formula:

$$T_p = T_b + T_a + T_{t.s.} + T_{o.s.} + T_{br},$$

where T_p = the time norm per piece (piece norm);
T_b = basic machine time;
T_a = auxiliary time;
$T_{t.s.}$= technical-servicing time;
$T_{o.s.}$= organizational-servicing time;
T_{br} = time taken by rest breaks and the satisfaction of natural needs.

The basic technological time T_b is the time spent directly in changing the geometrical shape of the product through its processing by cutting tools.

It is calculated on the basis of the dimensions of the processed surface and of the given cutting conditions.

The auxiliary time T_a is the time spent on various activities contributing to the basic work and repeated either with each part processed or after a definite number of parts. Starting and stopping the machine, clamping and releasing the processed part, and the displacement of the working members of the machine during its operation are examples of such activities.

It is obvious that the activities which together constitute the auxiliary time will differ depending on the type of work and on the design and dimensions of the machine, etc.

When calculating the technical norm, the auxiliary time is calculated from norms which take into account the above-mentioned factors.

The technical-servicing time $T_{t.s.}$ is the time spent on regrinding or replacing blunted tools, on adjusting or resetting the machine, on regrinding a blunted tool without removing it from the machine, etc.

The organizational-servicing time $T_{o.s.}$ is the time spent on setting up the tools at the workplace at the beginning of the shift and removing them at the end of the shift, on tidying up in general, and on cleaning and greasing the machine in the course of the shift.

The sum of the technical-servicing and the organizational-servicing times, which is the time required to keep the workplace in proper condition, is called the workplace-servicing time ($T_{t.s.}$ + $T_{o.s.}$).

Time for rest breaks (T_{br}) is established only for hard or otherwise strenuous work. In all other cases only the time required for the satisfaction of natural needs is taken into account.

The sum of the basic machine time and the auxiliary time ($T_b + T_a$) is called the **operational time.**

The technical-servicing time, the organizational-servicing time and the break time are calculated from norms established in dependence on the type of work and the size and the design of the machine.

In order to simplify the calculations, the norms are presented as coefficients relating these time costs to the operational time:

$$T_{t.s.} = \alpha (T_b + T_a),$$
$$T_{o.s.} = \beta (T_b + T_a),$$
$$T_{br} = \gamma (T_b + T_a),$$

where α, β, γ = are the coefficients taken from the corresponding norms.

Thus, the piece norm can be expressed as follows:

$$T_p = T_b + T_a + \alpha(T_b + T_a) + \beta(T_b + T_a) + \gamma(T_b + T_a).$$

The time norm should not include worktime losses stemming from excessive machining allowance, increased hardness, etc., nor should it include time losses resulting from rejects or other organizational-technical factors.

The calculated time defined as the total time required to produce a part or a batch of parts can be expressed by the formula

$$T_{p.c.} = T_p + \frac{T_{s.c.}}{n},$$

where $T_{s.c}$ = the setup and concluding time;
n = the number of parts in the batch.

The calculated time for a batch of parts is thus equal to

$$T_{ba.c} = T_p \cdot n + T_{s.c.}$$

The setup and concluding time is the time spent by the machine operator on familiarizing himself with the work and on preparing and setting up the machine and the tools and fixtures required, plus the time spent on removing the tool and fixtures after the whole batch of parts has been processed.

The setup and concluding time is calculated for the batch as a whole and it does not enter into the piece norm. The size of the batch has no influence on the magnitude of the setup and concluding time.

In mass production, and usually in large-series production as well, the organization of the workplace is such that the machine is preset and the materials, blanks, fixtures, tools and everything else necessary to do the job, are prepared in advance at the workplace.

In such cases the setup and concluding time is not taken into account at all in the machining norm.

The setup and concluding time is calculated from plant standards in dependence on the type of production, the work organization, the size of the machines, the means of setting the fixtures and parts and the number of tools participating, etc.

By reducing the number of the individual components of the technical norm, one increases the productivity. The basic machine time, for instance, can be reduced by imposing the most advantageous cutting conditions and by simultaneously processing several surfaces.

The auxiliary time can be reduced by combining positionings and setups, liquidating unnecessary setups tolerated for any reasons, and by reducing the time taken by any setup.

In watch manufacture the auxiliary times constitute a considerable fraction [of the total machining time], and the best way to reduce them is to combine operations and to use automatic machines.

TECHNICAL INSPECTION

Parts, assemblies or finished products which deviate for any reason from the drawings or the performance specifications must be regarded as rejects.

Rejected parts and assemblies cannot be used in the manufacture of the product, and rejected products cannot be put on the market.

Rejects cause great damage to the plant and to the national economy, leading as they do to increased expenditure materials, unnecessary time losses in production, and breakdowns in the fulfilment of the program.

An incessant struggle is accordingly waged against rejects and those responsible for rejects bear administrative and material responsibility for them.

Every plant has its technical inspection department (TID) charged with overseeing the quality of the plant's production at all stages, studying the causes leading to rejects, and formulating measures to prevent their appearance.

The TID staff inspects the materials used by the basic and the auxiliary (tool, maintenance) shops. They are also charged with checking all measuring instruments and tools used in production.

Distinction is made between operation inspection, sampling inspection, and final inspection. In some cases the process conditions are inspected as well.

Operation inspection is conducted after each operation for parts which undergo several operations.

Operation inspection is also carried out for important assembly operations.

In *sampling inspection* a fixed percentage of the parts in a batch is inspected, and the results of the inspection are considered as applying to the entire batch.

The inspection of process conditions is a preventative measure for operations where the conditions directly influence the final process result (such as heat-treatment operations).

The inspection of process conditions consists mainly in observing instrument readings.

In *final inspection*, important finished parts or finished products (completely assembled) are thoroughly inspected and tested, and the degree to which they correspond to the drawings (in the case of parts) or specifications (in the case of products) is ascertained.

When the inspection has been completed, a certificate is issued attesting to the quality of the accepted products.

One of the main objects of production inspection is the prevention of rejects.

The prevention of rejects is of particular importance in mass-production operations because the damage caused by rejects is particularly severe in such processes.

In high-output mass-production operations, such as cold stamping or turning on automatic lathes, the continuous operational inspection is frequently more labor-consuming than is the process itself.

It is, therefore, usual in such operations to inspect only some of the parts rather than all of them. This is called *statistical inspection*.

Statistical inspection, based on the methods of mathematical statistics, makes it possible to determine the quality of an entire batch on the basis of a limited number of inspected parts.

Statistical inspection is possible only if the machining process is inherently stable. By means of statistical inspection techniques the quality can be checked during production and accumulation of rejects is thus prevented.

If the spread of dimensions conforms to the law of normal distribution, the dimensions of 95% of the parts in the batch may differ from the average by no more than $\pm 2\sigma$, and the dimensions of 99.7% of the parts by no more than $\pm 3\sigma$ (see above).

Therefore, should the measured dimensions of several of the parts inspected differ by more than 3σ from the average, this would mean that the stability of the process has been upset, and that a systematic error leading to rejects has appeared.

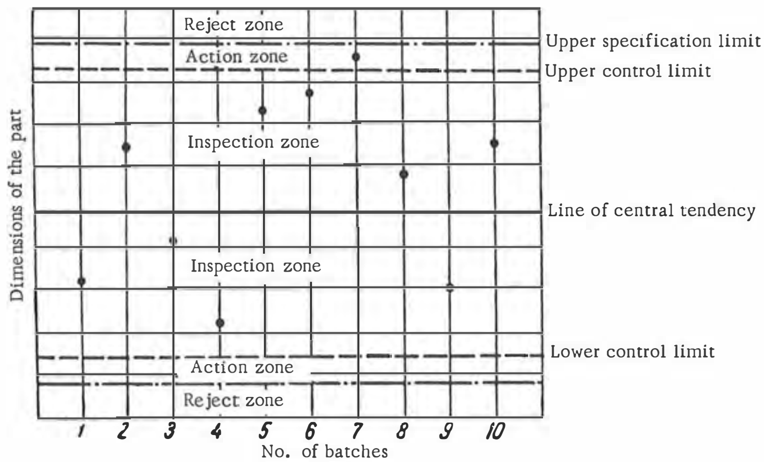


FIGURE 17. Control chart

A change in the machine setting, the blunting of the cutting tools or the disturbance of the working conditions could lead to such systematic errors.

The alarm signal thus given permits the timely detection and elimination of the cause of the disturbance thus preventing the mass production of rejects.

In statistical inspection, the inspector measures, at definite time intervals, a small number of parts (sample), taken from the machine in the course of its operation.

He then plots the results on a control chart (Figure 17), where the X-axis gives the sample number, and the Y-axis the value of the average for the sample of the magnitude measured. The line of central tendency is drawn through the middle of the diagram corresponding to the average value of the measured magnitude.

At a distance of 3σ on either side of this line the upper and lower control limit lines are drawn. Lines corresponding to the upper and lower specification limits are added (beyond the control limits).

The field of the diagram enclosed between the control limits is called the inspection zone.

The sectors enclosed between the upper and lower specification limits and their corresponding control limits are called the action zones. Beyond the specification limits are what are known as the reject zones.

If the points plotted by the inspector lie within the limits of the inspection zone, the process proceeds normally and the dimensions of the parts are within the range limits ($\pm 3\sigma$).

If points fall in the action zone, a factor has appeared which disturbs the normal course of the process. Although the specification limits have not yet been exceeded and there are therefore no rejects, the disturbing factor must be sought out and eliminated in order to prevent the possible production of rejects.

Points falling outside the specification limits indicate the complete breakdown of the process and necessitate the immediate stoppage of work.

The method of statistical inspection described is called the control-chart method for average size.

Other methods of statistical inspection exist, such as the method of the control chart for range*.

The statistical inspection methods are described in greater detail in the specialized literature.

Statistical inspection methods considerably reduce the size of the inspection staff a plant requires, shorten the production cycle (the parts pass directly from operation to operation), reduce measuring-instrument outlay (especially for gages), and makes available to the engineer valuable material, in the form of control charts, for the analysis of the technological process. On the basis of these charts, norms for the economic accuracy of equipment and tool-cost norms are established.

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* [In American practice, average-size and range-control charts are usually combined and are not considered separate methods.]

The designs of the product and of the production process are carefully worked out before starting large-series or mass production. The extensive preparatory work conducted is called p r o d u c t i o n p l a n n i n g.

Production planning comprises a whole range of measures undertaken at definite dates and includes the following five basic stages:

1. Design of the new products, or radical modification of an existing design (improvements).
2. Preparation and testing of experimental prototypes.
3. Planning the production process, and the equipment and tooling.
4. Manufacture of the production equipment.
5. Testing and development of the production process on a pilot batch.

In the watch industry, the design of new products or the radical modification of existing designs is conducted in the following stages:

Establishing the product specifications:

Working out the design drawings.

Working out technical specifications for the parts and subassemblies.

Preparing design drawings of gear profiles and special profiled parts.

Establishing the assembly procedures for the product.

The experimental prototypes are made in the experimental shop of the plant under the supervision of the senior designer. The drawings are corrected in the course of prototype manufacture, and the dimensions and tolerances are carefully coordinated.

Prototypes are thoroughly tested in the watch laboratory in order to ascertain whether the design meets the specifications.

Process planning consists in establishing the sequence of operations for each part and for assembly operations, selecting the equipment, machinery and tools, establishing the process conditions, calculating the time rates for the operations, and establishing the work category.

In working out the processes the rates of material consumption are calculated, the dimensions and shape of the parts at each operation are fixed, and the means and methods of inspection are established.

All these data are noted on engineering charts of different shapes and purposes, whose extent and contents depend on the type of production.

The most complicated among the operations are tested experimentally in the course of the process planning.

The production equipment is built by the plant's tool shop and the technological process planned is usually tested on a pilot batch.

The pilot batch is machined and assembled in the basic shops on machinery and at workplaces identical with those planned for the actual production process.

The punching dies, fixtures and other pieces of equipment are tested, and corrections are introduced into the engineering charts and the equipment drawings if necessary.

After the process has been tested, normal production begins. The testing of the planned process by means of a pilot batch is a necessary stage for mass and large-series production.

In order to shorten the time taken by production planning, many jobs are conducted in parallel by the chief production engineer's and the chief designer's departments.

Form for the operation chart for all machining operations

Plant	Operation chart No.	Chief production-engineer's department

Sketch and technical specifications

Product	Number of parts per product	Name of the part	Drawing No.	Symbol

Part of assembly	Name of the operation		Operation No.

Equipment	Inv. No.	Staff				
		Trade	Category	Servicing norm	Output norm	Rate per 1000 pieces

Basic material				
Name	Dimensions	Brand or grade	GOST	Requirement in kg per 1000 pieces

Auxiliary materials	GOST or TU	Requirement in kg per 1000 pieces	Auxiliary material	GOST or TU	Requirement in kg per 1000 pieces

Number (serial)	Name of passes	Fixture		Tool			
				Cutting		Measuring	
		Name	Drawing No.	Name	Drawing No.	Name	Drawing No.

Operating conditions					Time norm per 1000 pieces			
No. of the passes	Spindle rpm	Depth of cut	Feed	Number of parts machined simultaneously	Organizational-technical servicing	Machine	Auxiliary	Total

Shop No.	Receive from	Pass on to	Drawn up by	
			Checked by	
Next operation			Rated by	
			Approved by	

Production planning must be particularly thorough when assimilating new products.

Experience of watch plants has shown that production planning for a new type of watch takes roughly a year. Up to 75% of this time is taken by the preparation of the production processes. Sometimes the products are designed, and the drawings checked by building prototypes in departmental (branch) scientific research institutes or in special design offices. In such cases the plant need only work out the production process.

Equipment norms and typical technological processes, as well as other normative technical materials, are very important in reducing the time required to prepare the production processes.

The basic engineering document used in watch production is the operation chart. Its form for all machining operations is given below. Charts of a different kind are used for certain operations, such as cold stamping, metal coating, heat treatment, etc.

In addition to the operation charts, special lathe-adjustment charts are worked out for machining on automatic lathes.

On the basis of data from the operation charts, specifications and consumption norms for materials can be established, and summary process charts and lists of standard and special tools to be used can be drawn up.

The operation charts also serve as the basis for planning the special technological equipment, drawing up machining lists, and establishing acceptance standards for the parts.

The basic material used by the engineers in planning the technological processes, aside from the product drawings, includes: technical catalogues for the machinery, typical or standardized technological processes, GOST, departmental and plant standards for materials for punching dies, fixtures, cutting tools and measuring instruments, standards for technical rate-setting, and tariff guide for establishing work categories, etc.

In working out the processes, engineers must strive to use typical technological processes and standard tools and equipment wherever possible.

These aids reduce the time and work involved in the preparations for production, and lower the process cost.

If typical technological processes are used there is no need to plan new processes, it being sufficient to indicate the typical process to be used and the part dimensions. Standard tools are specified by listing their reference number.

In planning the technological process it is necessary to take into consideration the size of the production program, the available trained personnel, and the available equipment. Depending upon these conditions, the production process can either be split into simple operations each of which can be carried out on very simple machines with the aid of simple fixtures, or the processing can be done on a smaller number of complex machines.

The differentiation of operations is not advantageous in mass production, since both the piece time and the reject rate increase as a result of the increase in the number of workplaces; it is more advantageous to plan mass-production processes according to the principle of concentration of operations.

Processes drawn up according to this principle consist of complex operations carried out on complex machinery, such as automatic and unit-built machines, and require complex adjustments. Such arrangements result in a reduction in the number of operations, higher productivity, higher process accuracy, shortened production-cycle time, and reduced floor-space requirements.

Processes designed on the principle of concentration of operations represent a further step toward the transition to automated lines consisting of automated machines linked together into complex groups.

In automated lines the transfer of parts from one machine to the next takes place automatically, and the inspection of the processed parts is also done automatically and is included in the general work cycle.

Although the initial investments involved in the concentration of operations are much heavier than for simpler arrangements, these processes result in higher values for the engineering-efficiency figures.

The engineering efficiency of the process planned can be assessed by the following indexes:

a) product cost: composed of the cost of the materials and semifinished products and the wage and overhead expenses in the shops and the plants;

b) mechanization coefficient: the ratio of the rated machine time to the total working time, per unit product. The nearer the coefficient to unity, the higher the level of mechanization of the planned processes;

c) coefficient of equipment utilization: the ratio of the time during which the equipment is directly in use to the total time available in two shifts;

d) coefficient of the metal used per unit product.

These indexes are not sufficient, however, to allow comparisons to be made between the technological processes and production planning of two plants manufacturing similar products. To that end, additional indexes must be used.

Some of such engineering-efficiency indexes are:

1) labor productivity, defined as the annual output in rubles per production worker;

2) the yearly output in rubles per machine and 1 m^2 of floor space;

3) the yearly output in product units per worker, per machine, and per 1 m^2 of floor space.

Chapter II

METALS USED IN WATCH PRODUCTION

The mechanical properties of metals used in watch production must satisfy definite technical requirements (specifications) which have been worked out over a long period of time. In mass production, deviations from the specified properties lead to the deterioration of the quality of the watches produced and complicate the production process.

Chemical composition, mechanical properties and other requirements relative to the metals are defined in the All-Union Government Standards (GOST) and the interdepartmental technical specifications (TU).

A wide range of metal profiles and dimensions are used in the manufacture of watch parts. The number of metal grades is, however, relatively limited.

FERROUS METALS

The dimensions, tolerances and surface conditions of round wires and bars, as well as of rectangular bars and strips used in watch production are specified (with reference to GOST and TU) in the order specifications.

In exceptional cases the materials are processed to the required dimensions in the watch plants themselves: flat bars and strips are rolled and rods are drawn and then ground and polished.

The range of grade U10A and U7AV steel rods is given in Table 1, and Table 2 lists the range of high-carbon steel strips. Steel rods of a diameter of less than 3 mm can be supplied with a tolerance of 0.005 mm if required.

TABLE 1

Polished steel rods* (in mm)

Diameter	GOST or TU	Tolerance on diameter
From 0.2 to 0.45	GOST 2589-44	−0.015
" 0.5 " 3	The same	−0.02
" 3.05 " 6	"	−0.025
" 0.6 " 0.9	MPTU** 2283-49	−0.005
" 0.9 " 3	MPTU 2236-49	−0.01

* Abridged list.

** Metallurgicheskaya promyshlennost'. Tekhnicheskie usloviya (Metallurgical Industry. Technical Specifications).

The range of low-carbon cold-rolled steel strips is given in GOST 503-41.

The grades and chemical compositions of the carbon steels and special steels used in watch production are given in Table 3.

The mechanical properties of these steels are listed in Table 4.

The steels most widely used in watch production are grades U7AV and U10A.

An order for metals used in the manufacture of watch parts must specify the metallurgical state and characteristics of the metal in addition to the specification of mechanical properties. Thus, low-carbon cold-rolled steel strips (GOST 503-41) can be supplied with different hardnesses, depending on the degree of cold working resulting from rolling (Table 5). Degrees of hardness have also been established for rods: soft (symbol M), semihard (symbol PT), hard (T), very hard (OT).

Steel, aside from its mechanical properties, is characterized by its microstructure. Grades U10A and U7AV steel must have a microstructure of uniformly distributed fine-grain pearlite, corresponding to numbers 2-3 on the GOST 801-47 scale. A cementite lattice or lamellar pearlite are not acceptable. Nonmetallic inclusions, oxides and sulfides, are permitted for U10A steel within the limits of numbers 2 – 2a on scale No. 5 of GOST 801-47.

The sulfide inclusions must be uniformly distributed within the grains of the metal. Steel in a decarburized condition is not acceptable.

TABLE 2

Bright cold-rolled tool-steel strips* (in mm)
(according to GOST 2284-43)

Thickness	Thickness tolerance	Thickness	Thickness tolerance
0.1-0.15	−0.015	0.95-1.35	−0.06
0.15-0.25	−0.02	1.35-1.75	−0.08
0.25-0.40	−0.03	1.75-2.30	−0.10
0.40-0.70	−0.04	2.30-3.0	−0.12
0.70-0.95	−0.05		

* High-precision strips

The surface quality of the steel and its tolerances are of great importance in watch production. In most cases these parameters directly influence the quality of the parts and the production process. Thus, the yoke and the bridge of the hand-setting movement, for example, are blanked from a strip with final thickness dimensions and a surface suitable for plating. Less important parts, which are not subjected to heat treatment (hardening), are manufactured from rods and strips of grades 10 and 50 steel. Most turned parts and blanks, including those to be hardened, are made from rods of grade U7AV steel (automatic). Owing to the presence of sulfur and phosphorus in this grade of steel, it machines easily and is particularly suitable for fine threading.

Its high sulfur content, however, reduces its corrosion resistance and makes it brittle, Critical parts, such as the balance staff, are therefore preferably made of grade U10A steel. U8A steel strips are supplied in a hardened state and are used for the manufacture of flat springs.

Grade E1699 steel is characterized by a high corrosion resistance. Its machinability in turning and drilling is lower than that of grades U7AV and U10A, reducing machine output by roughly 10%. This steel is supplied with a polished surface. Grade 1Kh18N9 steel is used mainly for external parts such as covers, etc. This steel is very hard and tough, which makes its machining very difficult.

TABLE 3

Chemical composition of steel grades used in the manufacture of watch parts

Steel grade	GOST or TU	Chemical composition, in %						
		Carbon	Manganese	Silicon	Sulfur	Phosphorus	Nickel	Chromium
10	GOST 1050-52	0.07-0.015	0.35-0.65	0.17-0.37	0.045	0.04	0.30	0.15
50	The same	0.47-0.55	0.50-0.80	0.17-0.37	0.045	0.04	0.30	0.30
U8A	GOST 1435-54	0.75-0.84	0.25-0.30	0.30	Not more than 0.02	0.03	-	-
U10A	GOST 1435-54	0.95-1.04	0.15-0.30	0.30	Not more than 0.02	0.03	-	-
U7AV	MPTU 2242-49	0.7 - 0.8	0.4-0.7	Not more than 0.3	0.16-0.24	0.04-0.08	Not more than 0.25	0.25
1Kh18N9	GOST 5632-51	$\leqslant$0.14	$\leqslant$0.8	$\leqslant$2.0	0.03	0.035	8.0-11.0	17.0-20.0
EI699	ChMTU* 4825-54	0.32-0.4	0.4-0.7	$\leqslant$0.7	0.2-0.3	0.02-0.05	-	12.5-14

* [Chernaya metallurgiya. Tekhnicheskie usloviya (Ferrous Metallurgy. Technical Specifications)]

TABLE 4

Mechanical properties of steel grades used in the manufacture of watch parts

Steel grade	GOST or TU	Ultimate tensile strength, in kg/mm^2			Percentage elongation		
		rods		strips and flat bars	rods		strips and flat bars
		up to 4 mm	above 4 mm		up to 4 mm	above 4 mm	
10	GOST 503-41	-	—	28-80	-	-	4-30
50	1982-50	Not more than 80	70		-		-
	2284-43	-	-	75-110	-	-	1.5
U8A	GOST 2283-43	-	-	75-120	-	-	Not less than 1
U10A	MPTU 2242-49	80-90	70-80	75-120	4	7	Not less than 1
U7AV	MPTU 2242-49	80-90	70-80	-	Not less than 4	7	-
1Kh18N9	ChMTU 3715-53	-	-	Not more than 72	-	-	Not less than 40
EI699	ChMTU 4825-54	-	70-75		-	-	Not specified

TABLE 5

Mechanical properties of low-carbon cold-rolled steel strips (GOST 503-41)

State	Symbol	Ultimate tensile strength, in kg/mm^2	Percentage elongation
Very soft	OM	28-40	30
Soft	M	33-45	20
Semisoft	PM	38-50	10
Reduced hardness	PT	42-55	4
Hard	T	50-80	Not specified

NONFERROUS METALS

The nonferrous metal most widely used in watch production is brass. Plates and bridges, gears, cases, mainspring barrel caps, dials and other parts are made of brass.

German silver (nickel silver) occupies second place in importance. Case parts, the balance-wheel rim and other parts are made from it. Copper, tombac, and aluminum are used to a small extent.

Flat bars and strips of grade LS63-3 brass are listed in Table 6; Table 7 gives the range of brass wire of grades LS59-1, L62 and LS63-3.

TABLE 6

Flat bars and strips of grade LS63-3 lead brass (in mm)
(according to GOST 4442-48)

Strip thickness	Tolerance		Strip thickness	Tolerance	
	standard	high-precision		standard	high-precision
0.18-0.23	-0.03	-0.02	1.0-1.1	-0.08	-0.06
0.25-0.30	-0.04	-0.02	1.2-1.4	-0.09	-0.06
0.35-0.38	-0.04	-0.03	1.5-1.7	-0.10	-0.08
0.40-0.47	-0.05	-0.03	1.8-1.9	-0.12	-0.08
0.50	-0.06	-0.03	2.0-2.5	-0.12	-0.10
0.55-0.60	-0.06	-0.04	2.75-3.0	-0.14	-0.12
0.65	-0.06	-0.05	3.25-3.5	-0.16	-0.12
0.70-0.85	-0.07	-0.05	3.75-4.0	-0.18	-0.12
0.90-0.95	-0.08	-0.05	4.5-5.0	-0.20	-0.14

It should be noted that the tabulated data presented refer to the period 1954 to 1955 and that mechanical properties and attainable accuracy are constantly being improved.

The chemical compositions of the basic grades of nonferrous metals used in the manufacture of watch parts are given in Table 8.

In order to improve machinability, lead is added to LS59-1 and LS63-3 brass and to German silver MNTsS63-17-18-2.

Nonferrous metals must satisfy the requirements specified by GOST and VTU and presented in Table 9.

Flat rods and strips of LS63-3 lead brass are supplied, according to the TsMTU 4589-55 specifications, with the following mechanical properties:

semihard - 45 – 65 R_C, scale B;

hard - 65 – 90 R_C, scale B.

Brass grades L62 and L68 are used for the manufacture of parts by drawing or bending, since they have good plasticity and can be worked without failure.

TABLE 7

Brass wire (in mm) (according to GOST 1066-50)

Wire diameter	Tolerance		Wire diameter	Tolerance	
	standard	high-precision		standard	high-precision
0.10-0.25	-0.02	-	1.0-1.1	-0.04	-0.03
0.30	-0.03	-0.02	1.2-1.9	-0.045	-0.04
0.35-0.50	-0.03	-0.025	2.0-2.9	-0.055	-0.04
0.55-0.60	-0.035	-0.025	3.0	-0.06	-0.04
0.65-0.90	-0.035	-0.03	3.2-4.8	-0.06	-0.05

Remarks: The tolerances can be narrowed if required: for diameters up to 2.5 mm — down to 0.01 mm,
" " " " 4.8 mm — down to 0.02 mm.

TABLE 8

Chemical composition of nonferrous metals used in the manufacture of watch parts

Grade	GOST or TU	Chemical composition						
		Copper	Lead	Zinc	Nickel	Iron	Antimony	Bismuth
Brass LS59-1	GOST 1019-47	57-60	0.8-1.9	Balance	-	0.5	0.005	0.002
Brass L62	"	60.5-63.5	0.03	"	-	0.10	0.005	0.002
Brass LS63-3	"	62-65	2.4-3	"	-	0.10	0.005	0.002
Brass L68	"	67-70	0.03	"	-	0.10	0.005	0.002
German silver MNTsS 63-17-18-2	TUTsMO 6-42-51	Balance	1.6-2	17-19	16.5-18	-	-	-

When machined, these types of brass develop large burrs, which are inadmissible in watch production.

LS59-1 brass contains lead (more than 1 %), which makes it more suitable for machining.

LS63-3 brass, containing up to 3 % lead, has even better machinability and also higher hardness and brittleness. The hard and very hard brasses of this grade have a very good surface quality after being machined.

LS63-3 brass is used in the manufacture of important watch parts which require considerable machining.

Less important parts or parts requiring less machining are manufactured from LS59-1 brass.

Brass of all grades lends itself easily to plating.

Leaded German silver has much poorer machinability than has brass; it is harder and also tougher. Its surface quality after machining is therefore poorer than that of brass and its tendency to form burrs is more pronounced.

Some of the special alloys used in watch production are a nickel alloy for the spiral springs (hairsprings) of pocket- and wristwatch balance wheels, beryllium bronze and cupronickel.

TABLE 9

Mechanical properties of the nonferrous metals used in watch production

Grade	GOST or VTU	Ultimate tensile strength, in kg/mm^2, not less than				Percentage elongation, not less than			
		Soft (M)	Semihard (PT)	Hard (T)	Very hard(OT)	Soft (M)	Semihard (PT)	Hard (T)	Very hard(OT)
Wires, diameter between 2 and 5 mm									
LS59-1	GOST 1066-50	35	-	45	-	30	-	5	-
L62	GOST 1066-50	35	40	45	-	30	10	2	-
LS63-3	TU 303-46	-	-	50-60	60-70	-	-	1.5	0.5
Rods, diameter above 5 mm									
LS59-1	GOST 1066-50	35	-	43	-	30	-	8	-
L62	GOST 1066-50	35	36	41	-	34	12	5	-
LS63-3	TU 303-46	-	-	50-60	60-70	-	-	1.5	0.5
Sheets									
L62-T	TUTsMO 6-29-50	Drawing depth, according to the Eriksen test, from 1 to 3 mm							
Ribbons									
LS59-1	GOST 2208-49	35	-	45	-	25	-	5	-
L62	GOST 2208-49	30	38	42	60	35	20	10	2.5
L68	GOST 2208-49	30	35	40	50	40	25	15	4
Strips									
LS59-1	GOST 931-52	35	-	45	-	20	-	5	-
L62	GOST 931-52	30	35	42	-	40	20	10	-
L68	GOST 931-52	30	35	40	-	40	25	15	-

The nickel alloy N35KhMV used for hairsprings is supplied in the form of wires of 0.26-0.30 mm diameter having an ultimate tensile strength of 78 to 85 kg/mm^2 and a percentage elongation of 17 to 20%.

These wires are drawn to the required gage (0.055; 0.07; 0.075 mm) at the watch plants, after which they are subjected to flattening by rolling.

The temperature coefficient of this alloy is 0.3 to 0.5 sec per 1° C, which means that when the temperature varies by 1°C, the modulus of elasticity of the spiral changes by a magnitude which will cause a variation of 0.5 sec in 24 hours. The modulus of elasticity of the alloy E = 18,500 to 19,500 kg/mm^2 and the chemical composition are defined in the MPTU 3404-53 specifications.

The alloy must satisfy high requirements as regards its structure: the size of the (dispersed) carbides must not exceed 6 μ.

Grade B-4 beryllium bronze is used in the manufacture of the balance-wheel rim of watches and has the following chemical composition: 2.26 % beryllium, 0.40 % nickel, 0.42 % tellurium, the balance being copper.

TABLE 10

Mechanical properties of beryllium bronze, brass and German silver

Alloy	Brinell hardness, kg/mm^2	Ultimate tensile strength, kg/mm^2	Coefficient of linear expansion
Brass LS63-3	130--150	43—54	19×10^{-6}
German silver 63-17-18-2 . . .	140--180	38—45	18.4×10^{-6}
Beryllium bronze B-4	340	110	16.5×10^{-6} (after aging)

The choice of bronze as the material from which the balance wheel of pocket- and wristwatches is made is based on the following properties of this alloy:

a) high hardness, reaching $340\,kg/mm^2$ (H_B = 340), with a highly stable fine-grain structure, a fact which eliminates the tendency to distort, during or after machining, assembling and adjusting;

b) small coefficient of linear expansion (16.5×10^{-6}) as compared with brass and German silver. This makes it possible to lower the total temperature coefficient of the system balance wheel – spiral;

c) high corrosion resistance.

The mechanical properties of the B-4 bronze are presented in Table 10, together with those of brass and German silver.

A small addition of tellurium improves the machinability of B-4 bronze to the extent that it approaches 80 % of the machinability of German silver.

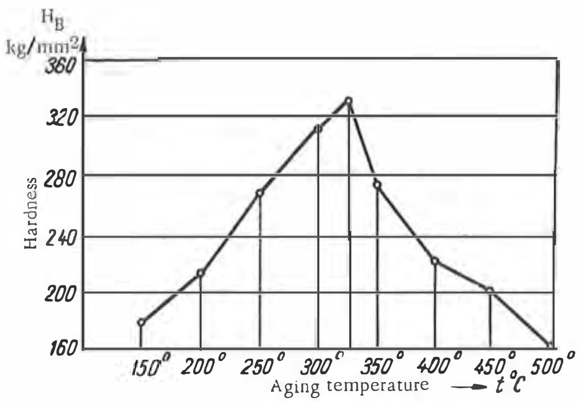


FIGURE 1. The hardness H_B of beryllium bronze as a function of the aging temperature

The heat treatment of bronze consists in heating to between 780 and 800°C, quenching in cold water, and tempering for several hours at 300 to 325°C. As a result of precipitation hardening, which takes place at a temperature of 300 to 325°C, the beryllium bronze loses the plasticity it had after quenching and becomes hard. Quenched beryllium bronze has a hardness H_B = 100; after aging the hardness is H_B = 325 — 340.

Aging of the bronze at temperatures above 325°C leads to a decrease in hardness, as can be seen from Figure 1.

Cupronickel is used for the manufacture of the cases of the wristwatches of the "Zvezda" brand. It contains, according to GOST 492-52, 20 to 28% nickel, the balance being copper. Its mechanical properties are, according to GOST 5187: ultimate tensile strength from 30 to 40 kg/mm^2, elongation 2.5%.

Cupronickel strips are supplied, as are brass strips, either to normal accuracy standards or as precision strips according to GOST 5187-49.

Strips of thickness up to 0.30 mm are not subjected to tensile tests, and their technological properties are established by a drawing test.

METAL TESTING

The metals delivered to the plant are subjected to sampling tests for chemical composition, mechanical and technological properties, as well as for their metallurgical structure, in accordance with GOST or VTU.

Depending upon their final use, the metals are subjected to the whole set of tests or only to some of them. The metals are certified as fit for use in production after satisfactory results have been obtained from the tests.

The metal tests are classified as chemical, mechanical, technological, metallographic, or special tests.

The chemical tests are conducted in the plant laboratories and consist in the analysis of the chemical composition of the metal for the purpose of determining the percentage of the various components.

This analysis is called an assay and is conducted on a small sample, cut from the bar or strip.

The determination of the chemical composition of metals by chemical methods is a lengthy process; however, in many cases, it suffices to determine the percentage content of only those components which decisively influence the properties of the alloy: carbon in carbon steel, carbon and sulfur in U7AV steel, lead in LS63-3 brass, etc.

The percentage content of certain components can in such cases be determined rapidly, although less accurately than by chemical analysis, by use of spectral analysis. The instrument used for this purpose is the SL-3 spark spectrograph.

The determination of the chemical composition using the spark spectrograph takes not more than a few minutes, since it is nondestructive and can be conducted directly on the metal bar or strip to be tested.

The mechanical tests serve to determine the ultimate tensile strength (U. T. S.), the percentage elongation, and the hardness. The tensile-test specimen (1) of given dimensions and shape (Figure 2), is gripped at both ends (2 and 3) and is set under tensile stress by the machine. The test specimen is stretched under the continuously increasing load, its length increases, and its cross section decreases.

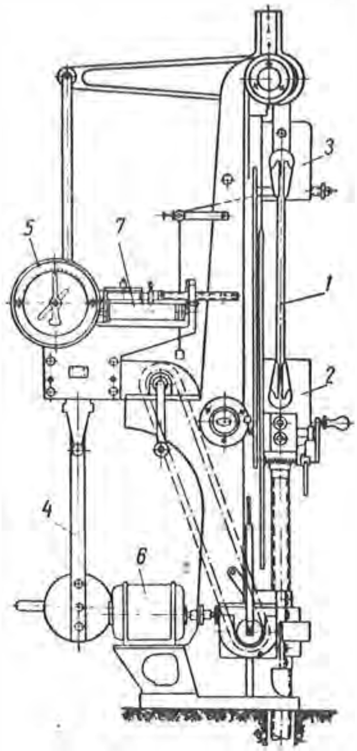


FIGURE 2. The P-5 machine for tensile testing

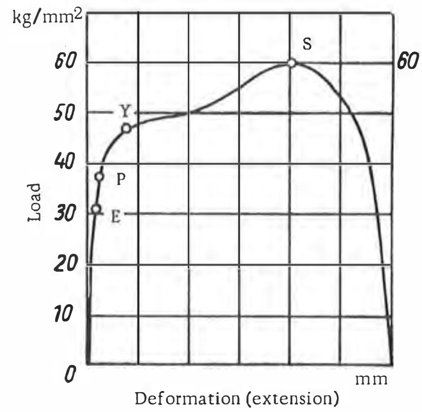


FIGURE 3. Deformation diagram of U10A steel (in the annealed state)

If we plot a load - deformation graph (Figure 3), we obtain a diagram with four characteristic points E, P, Y, S. A straight section, up to the point E follows Hooke's law with the deformation proportional to the load. Between point E and point Y this proportionality is disturbed, and the curve inclines to the right. Beyond point Y the test-specimen length increases with almost no increase in the load, the metal, as it were, flowing. The load reaches a maximum at point S, which corresponds to the ultimate tensile strength, after which a neck appears on the test specimen, and finally fracture occurs. The fracture takes place on a smaller cross section and under a smaller load than the maximum.

The mechanical properties of the metal are defined by the points E, P, Y, S.

The elastic limit (point E) is the maximum stress which produces no residual deformation or some predetermined, very small, value of residual deformation (Figure 3). It is designated by σ_E.

The proportional limit (point P) is the stress at which the elongation ceases to be proportional to the stress. It is designated by σ_P.

The yield strength or point (point Y) is the stress at which further deformation (elongation) of the specimen begins to take place with no further increase in load. It is designated by σ_Y.

The ultimate tensile strength (point S) is defined as the ratio of the maximum load recorded during the test, to the initial cross section of the test specimen. It is designated by σ_S and defined by the formula

$$\sigma_S = \frac{P_{max}}{f_o},$$

where P_{max} = maximum load;
f_o = initial cross section of the test specimen.

The percentage elongation is the residual deformation as a percentage ratio of the initial test-specimen length. It is designated by δ and defined by the formula

$$\delta = \frac{l - l_o}{l_o} \cdot 100,$$

where l = length of the deformed test specimen;
l_o = initial (gage) length of the test specimen.

The P-5 tensile testing machine (Figure 2) was designed for the static compression and tensile testing of metals. It can be adapted, by means of special attachments, to shearing, bending, and extrusion tests. The upper chuck of the machine is connected to a lever-pendulum dynamometer (4), on whose scale (5) the value of the load can be read. The operating loads of the machine are from 200 to 5000 kg. The machine has four scales:

0—50 kg, with a scale division of	2 kg
0—100 kg, " " " "	5 "
0—250 kg, " " " "	10 "
0—500 kg, " " " "	10 "

The lower chuck is powered by means of the electric motor (7) and a manual drive is also provided. The recorder (7) records the deformation of the specimen on paper.

The allowable error in the readings is 1% of the load.

The hardness test is widely applied in mechanical tests. Both nonhardened and hardened parts are tested for hardness. Chemical analysis and tensile tests are time- and work-consuming processes, and are destructive of the specimens. Hardness tests, on the other hand, take only several minutes and are basically nondestructive. The instruments used for hardness tests are simple and do not require foundations. The tests can be run inside the storeroom or in the heat-treatment shop.

The basic hardness tests are the Brinell test, conducted on the PBM tester, and the Rockwell test, carried out on the RV apparatus. The PBM tester is used for testing nonhardened metals. In the Brinell test, according to OST 10241-40, a steel ball is pressed into the metal to be tested, and the diameter of the indentation is measured by means of a magnifying glass or a microscope. The Brinell hardness is defined as the load divided by the spherical surface of the impression (Figure 4). It is designated as H_B and calculated using the following formula:

$$H_B = \frac{P}{F} = \frac{P}{\frac{\pi D}{2}(D - \sqrt{D^2 - d^2})} = \frac{2P}{\pi D\,(D - \sqrt{D^2 - d^2})},$$

where H_B = the Brinell hardness, in kg/mm^2;
P = the load on the steel ball, in kg;
D = the diameter of the steel ball, in mm;
d = the diameter of the imprint, in mm;
F = the surface of the imprint;

In the PBM tester the load is transmitted from the weights (5) to the steel ball through a lever system (Figure 5).

To begin with, the beam (1) rests on the roller of the connecting rod (2). When the electric motor is switched on, the connecting rod drops and the load (5) is transferred to the ball (3) which indents the specimen or part tested. The surface of the specimen must be flat in order that the edges of the imprint be clearly visible and given to accurate measurement by means of a microscope.

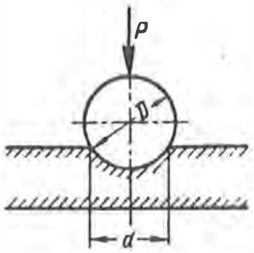


FIGURE 4. Scheme of the Brinell hardness test

The magnitude of the load, the diameter of the ball, and the length of the time during which the specimen is kept under load (i.e. the load-application time) are determined from Table 11.

The specimen to be tested is placed on the table of the PBM tester and applied against the ball (to a given depth) by turning the handwheel (4). The electric motor is then switched on and the main load is applied to the steel ball. At the end of the specified load-application time the electric motor is automatically switched off and the load is removed. The table is lowered by means of the handwheel, the specimen is removed, and the imprint diameter measured.

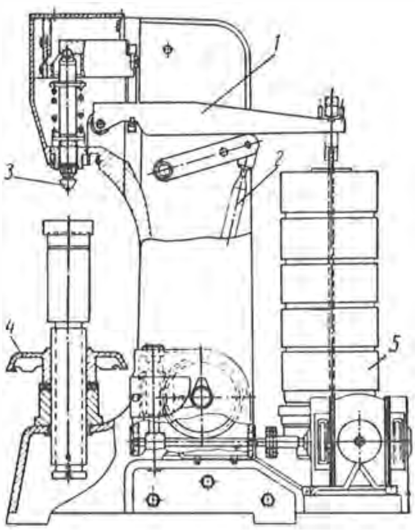


FIGURE 5. PBM tester for Brinell hardness tests

The need for subsequent calculations can be avoided by using tables which give the values of H_B as a function of the imprint diameter for given values of load and ball diameter. The values of H_B corresponding to a load $P =$ $= 3000$ kg and a 10 mm diameter steel ball are given in Table 12.

TABLE 11

Conditions for Brinell tests

Metal	Hardness range, kg/mm^2	Thickness of the test specimen, mm	Ball diameter, mm	Load, kg	Load-application time, sec
Ferrous metals	140-450	More than 6 From 3 to 6 Less than 3	10 5 2.5	3,000 750 187.5	10
The same	Up to140	More than 6 From 3 to 6 Less than 3	10 5 2.5	3,000 750 187.5	30
Nonferrous metals and alloys (copper, brass, bronze, etc.)	31.8-130	More than 6 From 3 to 6	10 5	1,000 250	30
Nonferrous metals and alloys (aluminum, bearing alloys, etc.)	8-35	Not less than 6	10	250	60

When soft materials or thin parts are tested, the load and the diameter of the ball are reduced so as to avoid penetration of the indenter through the specimen. Brinell hardness tests give reliable results for hardnesses up to $H_B = 350$ kg/mm^2. When metals of higher hardness are tested the ball is liable to become deformed (owing to its insufficient hardness).

The Rockwell test (see Figure 6) is suitable for both soft and hardened metals. It consists in forcing into the metal either a steel ball of 1.588 mm diameter or a conical diamond indenter with an apex angle of 120°.

The ball is used for testing soft metals, and the diamond cone for measuring hardened parts.

Rockwell hardness is determined from the difference between the depths of penetration of the diamond cone (or the steel ball) under the action of two consecutive loads – an initial and a major load. The load is applied by the beam (1) on which weights (2) are suspended. A turn of the crank (3) connects the load and transfers it to the indenter (diamond cone or steel ball) (4), which is thus forced into the surface being tested. The depth of penetration is measured by the dial indicator (5).

The design of the apparatus permits direct reading of hardness on the indicator scale.

The method for conducting Rockwell tests has been standardized (OST 10242-40). The tests can be conducted using one of the following three indicator scales (Table 13).

The external (black) scale of the indicator is used for readings on scales A and C.

The internal red scale serves for scale B. Hardness values according to these scales are designated H_{RA}, H_{RB}, H_{RC}*. Scale A is used for testing

* [According to American usage: R_A, R_B, R_C.]

metals of hardness beyond H_{RC} = 67. The working range of scale B lies within the limits H_{RB} = 25 and H_{RB} = 100, and of scale C between the limits H_{RC} = 20 and H_{RC} = 70.

TABLE 12

Brinell hardness numbers (P = 3000 kg, D_{ball} = 10 mm)

Diameter of imprint d	Hardness H_B	Diameter of imprint d	Hardness H_B	Diameter of imprint d	Hardness H_B
2.4	652	3.55	293	4.70	163
2.45	627	3.60	286	4.75	159
2.50	600	3.65	277	4.80	156
2.55	578	3.70	269	4.85	153
2.60	555	3.75	262	4.90	149
2.65	532	3.80	255	4.95	146
2.70	512	3.85	248	5.00	143
2.75	495	3.90	241	5.05	140
2.80	477	3.95	235	5.10	137
2.85	460	4.00	229	5.15	134
2.90	444	4.05	223	5.20	131
2.95	430	4.10	217	5.25	128
				5.30	126
3.00	418	4.15	212	5.35	124
3.05	402	4.20	207	5.40	121
				5.45	118
3.10	387	4.25	202	5.50	116
3.15	375	4.30	196	5.55	114
3.20	364	4.35	192	5.60	112
3.25	351	4.40	187	5.65	109
3.30	340	4.45	183	5.70	107
3.35	332	4.50	179	5.75	105
3.40	321	4.55	174	5.80	103
				5.85	101
3.45	311	4.60	170	5.90	99
3.50	302	4.65	166	5.95	97

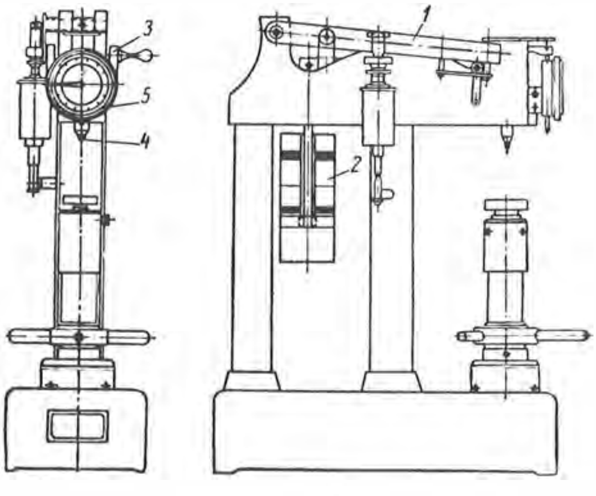


FIGURE 6. Apparatus used for Rockwell hardness tests

Rockwell tests take less time than do Brinell tests.

Another advantage of the Rockwell method is that the specimen surface suffers almost no damage, the indentations made by the steel ball or the diamond indenter being negligible.

The Rockwell hardness tester is suitable for testing specimens of a thickness not less than 1 mm on scale C, and not less than 2 mm on scale **B**.

TABLE 13

Rockwell-hardness scales

Symbol	Indenter	Initial load, kg	Final load, kg	Application
C	Diamond cone with apex angle 120° and of radius curvature 0.2 mm	10	10+ 140 = 150	Hard and heat-treated steels
A	The same	10	10+ 50 = 60	Superhard alloys, products with case-hardened, work-hardened surface, etc.
B	Steel ball of 1.588 mm diameter	10	10+ 90 = 100	Soft metals

Thinner specimens are deformed through the reverse side, and the hardness readings are distorted.

The Rockwell hardness has a relative value, and is not an absolute quantity. One division on the indicator scale corresponds to a depth of penetration of 2μ.

A definite relationship exists between the hardness values obtained by the Brinell method and those obtained by the Rockwell method (Figure 7).

As the machinability of a metal is not uniquely determined by its chemical composition and mechanical properties, the metals to be used in the manufacture of parts are subjected to technological tests.

Drawing test of sheet metals. Sheets and strips intended for drawing are subjected to this test.

The test specimen (1) is fastened to the apparatus (Figure 8) by means of the threaded sleeve (5). When the handwheel (7) is turned, the spindle (4) is displaced forcing the punch (2) into the metal. The metal is thus drawn through the die (3) until cracks appear. The punch and die are of standard form, and the appearance of cracks is observed through the mirror (6). The depth of draw up to the appearance of cracks serves as a mesure of the drawability of the metal.

Figure 9 presents three photographs of tested specimens. In Figure 9,a, the depth of draw, for a thick brass specimen, was 12 mm. Figure 9, b shows a 0.35 mm specimen drawn to a depth of 5 mm. In Figure 9, c, a 0.5 mm steel specimen has been drawn to a depth of 10 mm.

Strip material (steel, brass, etc.), which is to go into the manufacture of alarm-clock cases, airborne clock housings, etc., is first subjected to a drawing test.

A drawing depth of 11 to 12 mm has been established as the standard for 1Kh18N9 stainless steel, used in the manufacture of lids and bottoms for pocket- or wristwatches.

The conditions under which the drawing tests are to be carried out are specified by GOST 503-41.

Repeat-bending tests for round and square bars are carried out on the NG-1-2 apparatus (Figure 10).

The apparatus consists of a small bench-type vise (1), with exchangeable jaws (2), which clamp one end of the specimen. The other end is held by the carrier (4) of the rotating lever (3).

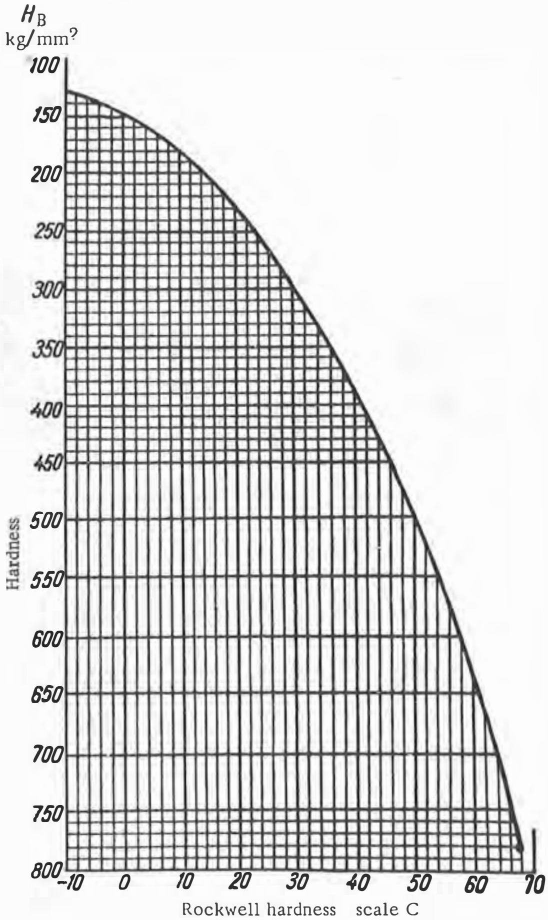


FIGURE 7. Relationship between Rockwell and Brinell hardness values

The test specimen is bent 90° alternatingly to the right and left. The number of bends to failure of the test specimen is characteristic of the ductility of the metal.

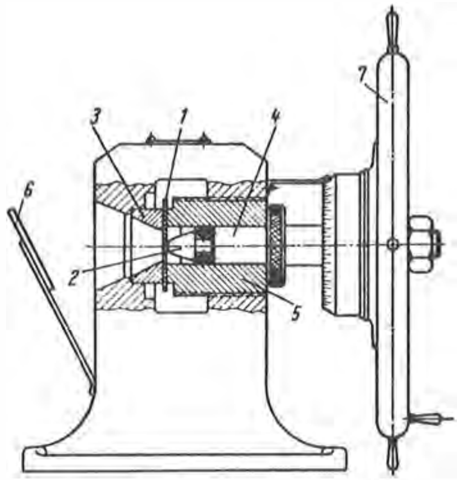


FIGURE 8. Apparatus for drawing tests

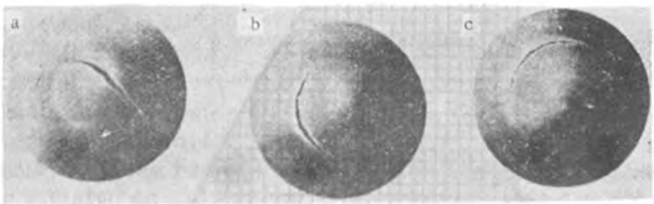


FIGURE 9. Drawing test specimens

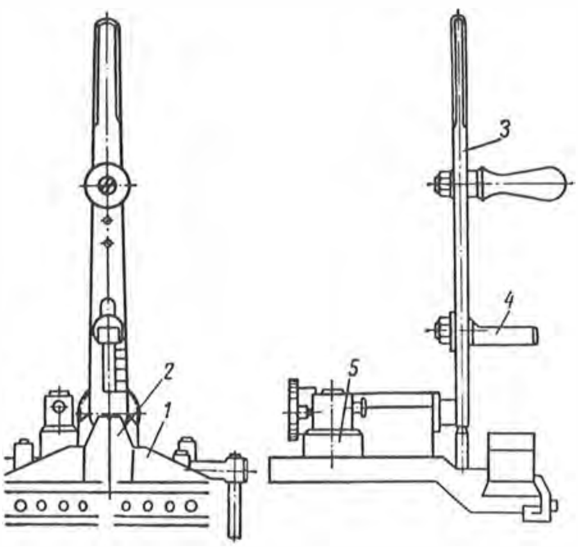


FIGURE 10. NG-1-2 apparatus for bending tests

The apparatus is suitable for testing round bars of diameters from 0.8 to 7 mm and flat bars of a thickness of up to 5 mm.

A counter (5) records the number of bends.

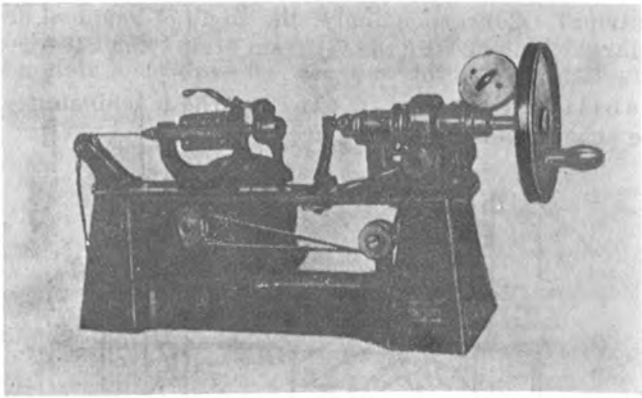


FIGURE 11. Apparatus for torsion-testing of wires

T o r s i o n t e s t s f o r w i r e are conducted on the K-1 (K-2, K-3) apparatus (Figure 11).

The wire is clamped in chucks in the head- and tailstock of the apparatus. The headstock chuck is rotated by an electric motor which is automatically switched off when the specimen fails. The number of turns to failure is recorded on a counter.

R e s i d u a l d e f o r m a t i o n (permanent-set) t e s t s. With heat-treated spring steel strips, the tensile, hardness and bending tests are only indirectly indicative of their quality, and do not define fully the elasto-plastic properties of the material.

FIGURE 12. Apparatus for testing the elasto-plastic properties of spring steel strips

These properties are determined by use of an apparatus (Figure 12) which measures the angle α of residual deformation. The apparatus scale is divided into 180°. The test specimen is clamped at one end to the mandrel of the apparatus, and the other end is set to the zero point of the scale. The test specimen is then wrapped around the mandrel by an angle of 180°. After 50 such bends the angle α is measured from the position of the test specimen on the scale, and the residual deformation determined from it.

In some variants of this apparatus the springback angle ($\beta = 180° - \alpha°$) is measured instead of the angle of residual deformation. The accuracy of this type of apparatus is by 5 to 6° lower than that of the device shown in Figure 12.

The springback properties for strips are given in the ChMTU 3680-53 specifications. The angle of springback for a 0.12 mm thick spring bent on a 5 mm diameter mandrel must not be less than 147°. For a 0.32 mm strip on a 20 mm diameter mandrel, this angle must not be less than 156° (for first-grade strips). Correspondingly, the angle of residual deformation must not be larger than 33° for the 0.12 mm strip, and 24° for the 0.32 mm strip.

Machinability test for metals. The machinability test is conducted on the apparatus shown in Figure 13.

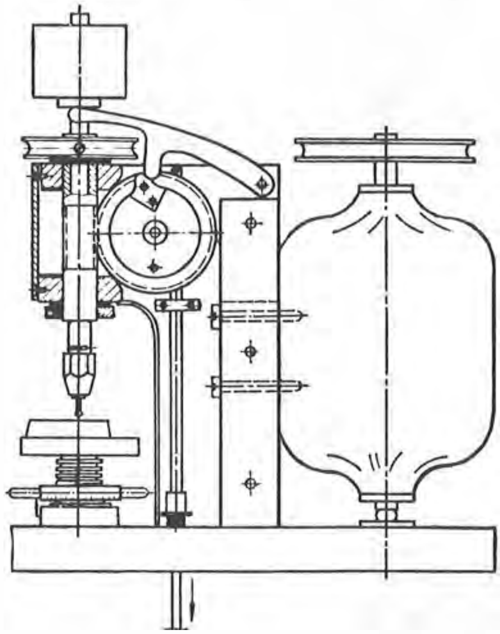


FIGURE 13. Apparatus for testing of metals for machinability

The test consists essentially in producing dimples (craters) in the metal by means of a pointed-end drill of 2.5 – 3.0 mm diameter and a point angle of 80 – 85° for brass, and 120 – 125° for steel.

The dimples are drilled under a specified axial load on the drill which is made to rotate for a given number of turns. After the chips have been removed, the diameter of the crater is measured by means of a graduated magnifying glass. The machinability can also be determined from the weight of chips.

The machinability of a given metal is determined as a percentage of the machinability of an accepted standard material. The above method is therefore of a comparative character.

Numerical values of the squared ratios of the diameters of the specimen and standard craters, respectively, are given in a special table.

The apparatus consists of a semiautomatic bench drilling press and a cam mechanism.

The constant (given) load is applied by calibrated weights carried by the spindle. The specified number of turns of the spindle for one test cycle is ensured by a cam mechanism lifting the spindle off the specimen. The load can be varied, depending upon the thickness and machinability of the material being tested.

Metallographic tests consist in the investigation of the microstructure of metals and alloys by means of suitable (metallographic) microscopes.

Chapter III

STAMPING PROCESSES

Stamping is one of the most advanced methods of metal processing and has many advantages over other processing methods such as turning, milling, drilling, etc. Complex parts can be stamped out in one stroke of the press to high accuracy and with stable dimensions. Stamping processes are characterized by a high output: various presses have between 60 and 420 working strokes per minute. Almost all kinds of stamping operations can be automatized.

Stamping processes play an important part in watch production. Of the 620 machining operations carried out on wristwatch parts, 125, or 20%, are stamping operations. The amount of work expended on these operations, however, represents only 7% of the total work expended on all the machining operations.

Stamping refers to the various technological operations executed (generally without formation of chips) on presses by means of stamping dies of various designs. The following stamping processes are used in watch production: blanking, piercing, dinking, shaving, bending, drawing, straightening, center punching, embossing and coining, marking, forming, combined punching, and sizing.

These operations are executed on crank, knuckle, friction and hydraulic presses.

The dies used in stamping operations are known, according to the operations executed by them, as blanking dies, shaving dies, etc.

BLANKING AND PIERCING

Blanking is the most widely applied among the stamping operations and is the initial operation in the manufacture of parts from flat bars or strips. It is applied not only as a separate operation, but also in conjunction with other stamping operations.

The blanking process is shown diagrammatically in Figure 1.

The blanking process can be divided into three stages (Figure 2).

First stage. When the press ram is lowered, the flat end of the punch presses the strip of material against the upper face of the die, then compresses the upper layers of the strip and penetrates into the metal.

The metal fibers suffer a slight compression and bending, and the metal begins to be forced into the die hole. At this stage, the stresses in the metal do not exceed the elastic limit.

S e c o n d s t a g e. During this stage, in which stresses go beyond the elastic limit, there occurs a further bending and stretching of the fibers, and they are cut by the sharp edges of the die. At the end of this stage, the stresses reach the ultimate shearing strength for the metal, and microfractures appear. The press force reaches its maximum.

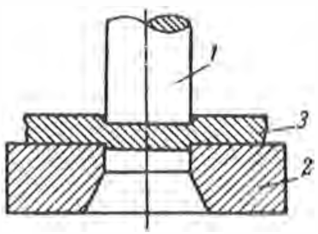


FIGURE 1. Schematic diagram of the blanking process

1- punch; 2-die; 3-stock.

T h i r d s t a g e. The beginning of this stage is characterized by the appearance of macrofractures near the cutting edges of the die and punch, and their propagating at a definite angle into the metal.

These fractures develop swiftly, and the blank separates from the strip.

If the clearance between the punch and the die opening is normal, the punch-side and die-side fractures will meet and form a common shearing surface.

If the clearance is too small, the directions of the fractures do not coincide, and the double shearing causes the formation of an extended burr on the product (Figure 3). If the clearance is too large, the blank will have rugged edges owing to the tearing of material in the clearance space.

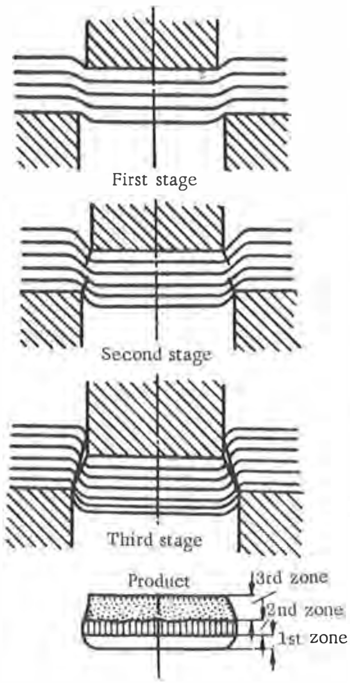


FIGURE 2. Stages of the blanking process

A graph showing the stresses in the metal as a function of the ram motion is given in Figure 4 for a steel strip of up to 4 mm thickness and of average hardness. The sector AB corresponds to the stage of elastic deformations and BC to the plastic deformation stage (up to the beginning of shearing). Point C corresponds to the maximum stress imposed on the metal during the blanking and sector CD indicates the rupturing stage. Sector DE gives the force which must be applied in order to overcome the friction when the part is ejected from the strip and forced through the die.

The three zones on the lateral surface of the part correspond to the three stages of the blanking process (Figure 2). The first zone, corresponding to the first stage, is slightly rounded off on the die side. The second zone is a cylindrical belt formed during the cutting of the fibers by the cutting edges of the die, and corresponds to the ram motion up to the appearance of shearing fractures. The third zone is a rough conical surface and corresponds to the stage of metal failure.

Clearance between punch and die. Clearance is the difference between the matching punch and die dimensions. The magnitude of the clearance required depends mainly on the material and the thickness of the part to be blanked.

Each material and thickness have their optimal clearance, defined as the clearance for which the directions of the shearing stresses from the punch and the die coincide, and for which the blanking force is a minimum.

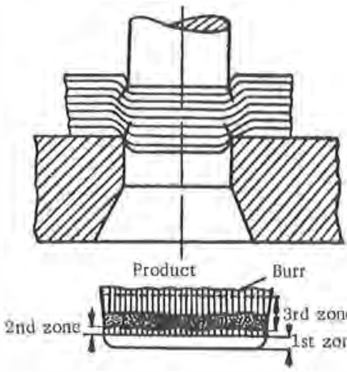


FIGURE 3. Shearing fractures and shape of the blank in the case of insufficient punch clearance

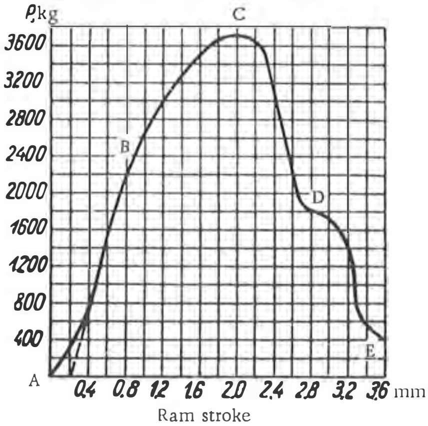


FIGURE 4. Graph of the stresses in the stamped metal as a function of the ram stroke (steel strip of a thickness of up to 4 mm and average hardness)

Despite the wide application of blanking operations, as yet there exists no theoretically substantiated method for determining the clearance. Empirical data are used in production practice.

Recommended clearances between the punch and the die for blanking dies are given in Table 1.

TABLE 1

Bilateral clearance between punch and die in % of the strip thickness

Strip thickness, mm	Clearance, %		
	brass and mild steel	steel of average hardness	hard steel
0.10—1	4	7	9
1.1—2	4.5	7	9
2.2—4	5	8	10
4.2—6	6	9	12

Optimum clearances vary between 5 and 12% of the strip thickness.

The values given are suitable for circular blanks. When blanking parts of a more complex shape, having sharp angles, the data given in the table must be adjusted up or down, depending on the actual shape of the part.

In blanking operations the required clearance is obtained at the expense of the punch size, the size of the blank being equal to the die opening. In piercing operations, on the other hand, the clearance is achieved by increasing the size of the die opening, as the size of the pierced hole is equal to the punch diameter.

Blanking Forces

The force P, required to blank out a part, depends on the shear area, equal to the perimeter of the blanked part multiplied by the stock thickness, and on the shear strength of the metal.

The force P is calculated using the formula

$$P = L \cdot s \cdot \sigma_s, \qquad (1)$$

where P = the force, kg;
L = length of the part perimeter, mm;
s = the thickness of the part, mm;
σ_s = the shear strength of the metal, kg/mm^2.

For circular parts $L = \pi D$, and (1) becomes

$$P = \pi \cdot D \cdot s \cdot \sigma_s.$$

If several punches operate simultaneously in the stamping die, the value of the total force P is equal to the sum of the forces calculated separately for each punch.

In a gang blanking die the blanking force is sometimes reduced by installing the punches at different heights, which ensures progressive blanking.

The value of σ_s for various materials can be found in the handbooks on stamping. The value of P also depends on the die design. If the die hole has a cylindrical portion, an additional force Q is necessary in order to force the blanks through the die (cf. below). The number of parts held in this cylindrical portion obviously depends on the height of the latter and on the thickness of the material. The force Q necessary for forcing through one part is on the average 3 to 5% of P. If the die has a tapered hole (see below), the part will not be retained, and no additional force is needed to force it through.

The magnitude of P decreases if the strips are lubricated and increases with a decrease in the clearance between the punch and die below the normal value. Blunted cutting edges on the punch and die also increase the force. P decreases by 5 to 7% when the strips are lubricated, and can increase by 15 to 20% with a decrease in the clearance. The blunting of the cutting edges likewise leads to an increase in P of 10 to 15%. The presence of buffer springs in the die also increases the required blanking force.

Owing to the above-listed factors, the actual value of the blanking force is higher by 20 to 30% than the value calculated by (1):

$$P_{act} = (1.2 - 1.3)\, P_{calc} \qquad (2)$$

Example of calculation of P. Let the part be a watch plate: the blanking diameter, 38 mm; the thickness, 3.2 mm; the material, brass; σ_s = 40 kg/mm^2.

$$P_{act} = 1.2\pi D s \sigma_s = 1.2 \cdot 3.14 \cdot 38 \cdot 3.2 \cdot 40 \approx 18.5 \text{ t}.$$

Center of pressure of the die. The blanking forces are applied along the cutting edges of the punch and die and are mutually parallel and perpendicular to the die plane.

The point of application of the resultant of all the forces acting during the blanking is called the center of pressure.

The center of pressure of a blanking die must coincide with the axis of the die shank mounted in the ram, as otherwise, lateral shearing forces will appear which can lead to uneven wear of the ram guides or of the die, uneven blunting of the cutting edges and, in the case of small clearances, even punch breakage or damage of the die.

In round parts the center of pressure coincides with the center of the blank. In parts of regular geometrical shape, such as squares and rectangles, the center of pressure coincides with the intersection of the diagonals.

In parts of any shape the center of pressure will always be located at the center of gravity of the contour of the part, calculated by assuming that the contour of the part to be blanked is a material line possessing weight.

There are several methods for the determination of the center of pressure.

A diagram of the simultaneous piercing of two holes of different diameters, having centers located on the X-axis, is shown in Figure 5, where the following designations have been adopted: D_1 = diameter of the smaller hole; D_2 = diameter of the larger hole; U_1 and U_2 = perimeters of the holes; σ_s = = shearing strength.

The forces P_1 and P_2 necessary for piercing the two holes, respectively, will be equal to

$$P_1 = U_1 s \cdot \sigma_s \,,$$
$$P_2 = U_2 \cdot s \cdot \sigma_s \,.$$

The forces P_1 and P_2 are applied at the centers of the corresponding circles. P_1 and P_2 are parallel and the magnitude of their resultant is therefore equal to their sum

$$P = P_1 + P_2.$$

The point of application of the resultant P is determined by setting the moments of the two forces equal

$$P_1 x = P_2 (l - x); \quad x = \frac{P_2 l}{P_1 + P_2}.$$

Substituting for P_1 and P_2 their values and canceling s, σ_s, π, we obtain

$$x = \frac{D_2 l}{D_1 + D_2}.$$

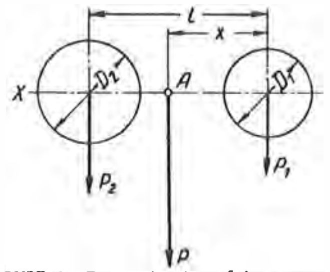


FIGURE 5. Determination of the center of pressure for a two-punch die

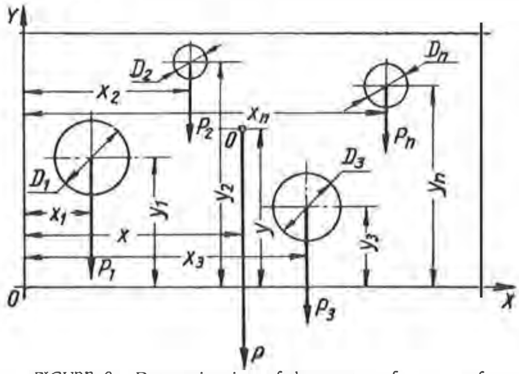


FIGURE 6. Determination of the center of pressure for a multi-punch die by the analytical method

It is seen from this expression that the center of pressure is uniquely determined by the blank perimeters or, in our case, by the diameters.

Generally, the position of the center of pressure is expressed as x and y relative to some point of reference in the plane of the drawing.

The diagram in Figure 6 shows the simultaneous piercing of holes of different diameters.

The resultant P of all the forces acting during blanking will be equal to

$$P = P_1 + P_2 + P_3 + \ldots + P_n.$$

Resorting to the theorem of statics, according to which the sum of the moments of the component forces relative to an axis is equal to the moment of the resultant relative to this axis, we obtain

$$P_1x_1 + P_2x_2 + P_3x_3 + \ldots + P_nx_n = P \cdot x,$$
$$P_1y_1 + P_2y_2 + P_3y_3 + \ldots + P_ny_n = P \cdot y.$$

Substituting P_1, P_2, P_3, P_n for D_1, D_2, D_3, D_n (or the perimeters U_i for contours of other shapes), we obtain the general formula

$$x = \frac{D_1x_1 + D_2x_2 + D_3x_3 + \ldots + D_nx_n}{P} = \sum_{i=1}^{i=n} \frac{D_ix_i}{P};$$

$$y = \frac{D_1y_1 + D_2y_2 + D_3y_3 + \ldots + D_ny_n}{P} = \sum_{i=1}^{i=n} \frac{D_iy_i}{P}.$$

This method for determining the center of pressure is an analytical method.

A graphical method for determining the center of pressure is also in use. It consists in finding the application point of the resultant of the system of parallel forces by means of a force polygon.

When blanking irregularly shaped parts, the contour of the part is broken up into parts (straight segments, arcs, etc.). Each section of the contour is treated as a material line and a vector proportional to its length (to a chosen scale) is applied at its center of gravity.

The coordinates of the center of pressure are determined, analytically or graphically, as the application point of the resultant of the system of parallel forces (vectors).

Layout. The blanking operation must be designed so as to ensure the most economic use of the metal. To that end the part must be laid out in the strip so as to minimize scrap.

Scrap resulting from punching small holes and waste of the metal at both ends of the strip is unavoidable, but their influence on the coefficient of metal utilization is small. The economy of the layout is basically determined by the amount of scrap left between the blanks which, in certain cases, is as much as 70%, only 30% of the metal being utilized usefully.

The economy of the layout is measured by the coefficient of metal utilization, defined by the formula

$$k_{\text{m.u.}} = \frac{F}{B \cdot t} 100,$$

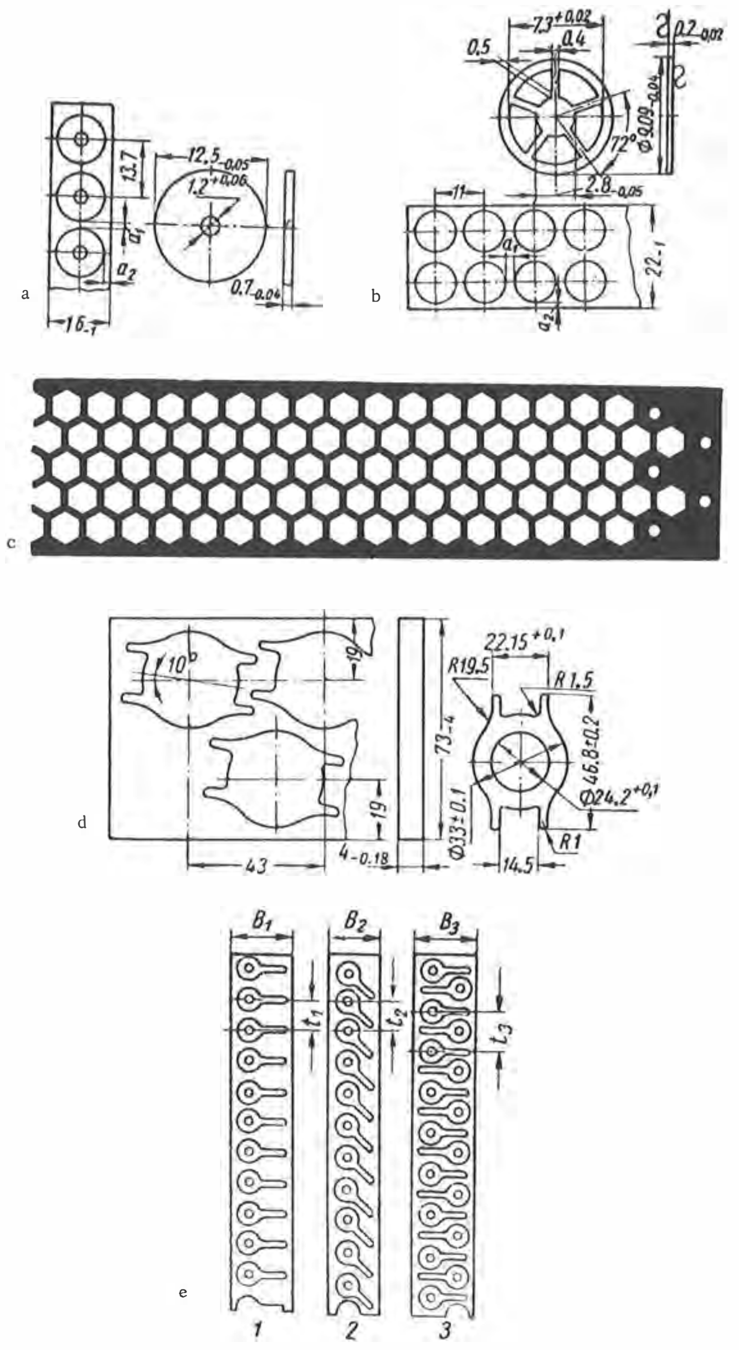


FIGURE 7. Examples of strip layout

where $k_{m.u.}$ = coefficient of metal utilization, %;
F = blank area, mm^2;
B = strip width, mm;
t = strip feed per blank, mm (distance between two homologous points of two adjacent blanks).

Several examples of layout are shown in Figure 7. Figure 7, a shows a single-row strip layout, as used in blanking and simultaneous piercing the winding wheel of wristwatches. The coefficient of metal utilization (neglecting the waste due to the punching of the holes) is 50%.

Figure 7, b shows a two-row strip layout used for blanking spoked wheels. The coefficient of metal utilization is 64%. Figure 7, c presents a five-row strip layout for blanking hexagonal nuts with simultaneous punching of holes. The blanks are arranged in a honeycomb pattern and the coefficient of metal utilization is 60%.

Figure 7, d shows a two-row strip layout for blanking case rims, with simultaneous punching of holes. The layout is economical for the given part, although the coefficient of metal utilization is only 33%.

In Figure 7, e three strip layouts for blanking alarm-clock regulators are shown. The coefficient of metal utilization is 32% in the first layout, 40% in the second, and 46% in the third.

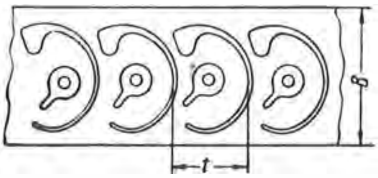


FIGURE 8. Blanking of two parts by two stamping dies from the same strip

Figure 8 shows the strip layout for blanking two different alarm-clock parts in two different stamping dies: the regulator is blanked after the blanking of the spring.

The staggered multi-row layout is most expedient for blanking round parts (washers, wheels, etc.). It should be kept in mind, when designing the layout, that in mass production a saving of several grams of metal per part adds up to tens of tons of metal.

The strip layouts can be designed in the following manner: the part is cut out of cardboard in several copies, in its full-size dimensions or to scale. Various arrangements are then tried, and the arrangement giving the smallest loss of material is selected. If the configuration of the part is such that there is always considerable scrap, it should be matched with another part of the same thickness and the two parts can either be made by the same die or separately by two dies.

A layout without scrap is possible for certain parts whose contours are made up of straight lines.

For parts with very narrow sections, such as clock hands, etc., an inverse layout can be used, in which the part remains in the strip in the form of a bridge while the blanked spaces between the parts constitute the scrap. The coefficient of metal utilization in such cases drops to 15 – 20%.

The strip layout for blanking wristwatch hands is shown in Figure 9. The thickness in section a-a is equal to 0.15 mm, and the width is 0.05 to 0.08 mm.

The stamping of this part is carried out as follows: the hole is pierced, the contour is blanked; the central section is cambered and the socket drawn; lastly, the hand is cut off from the lateral edges of the strip.

In designing the layout it is necessary to take into account the arrangement of the parts relative to the direction of the [rolling] grain in the material

The grain in strips is usually of longitudinal orientation but if the strips are cut from sheets it is possible to obtain transversally oriented grain.

There are parts which, due to their configuration, cannot be made with transversally directed grain. The stop-watch spring is an example (Figure 10); it will break after heat treatment if made with transverse grain. In such cases it is necessary to arrange the parts along the strip, although such a layout is less economical.

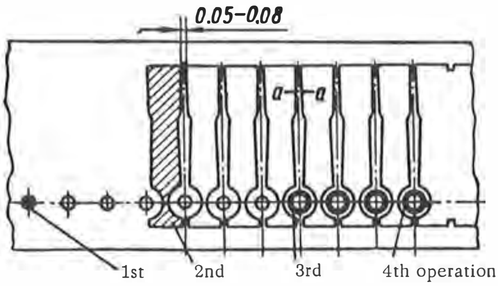


FIGURE 9. Layout for the blanking of wrist-watch hands

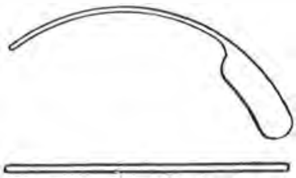


FIGURE 10. Stop-watch spring

When designing the layout it is necessary to take into account the existing assortment of standard strips (GOST). If a certain layout calls for strips of nonstandard width, it is likely that the extra cost of preparation of nonstandard strips will be higher than the economy achieved by the better layout. The striving for economy in the layout must not be allowed to lead to an increase in machining work and to the introduction of additional operations.

Blanking of sheets or strips leaves in the blank portions of metal called bridges which constitute waste. The width of these bridges depends on many factors, but mainly on the strip thickness and the metal strength. It is also influenced by the dimensions and configuration of the blanks, the means of strip feeding, the required accuracy, and the stamping-die design.

The width of the bridges is determined using empirical graphs (Figure 11) or tables.

The data given in Figure 11 must be multiplied by the following coefficients, depending on the material being stamped: 0.9 for steel of average hardness, 1.0 for hard steel, 1.2 for soft brass, 1.4 for aluminum.

If an automatic roll feed is used in the blanking process, the bridge values are multiplied by 1.2.

If the blanks are to be pressed back into the strip, the bridge width must be increased by 20%.

Scrap width a_2 at the strip edges is taken as equal to $1.2 - 1.5\,a_1$.

Elements of blanking dies. Most stamping operations in watch production are conducted on die sets provided with guidepins. A die set consists of the upper and lower shoes, the punch, the die, and other auxiliary components.

The shoes are two cast-iron plates on which all the other components of the die are mounted. The guidepins and the die block are mounted on the lower shoe, the punch and the shank, on the upper shoe.

When mounted on a press, the die set is fastened to the bolster plate of the press by means of straps and bolts.

The upper shoe is fastened to the press ram by its shank, whose head fits into the T-shaped slot of the transition shank fastened to the ram by bolts.

The shank head is made spherical in order to avoid the transmission of nonaxial forces from the press ram to the upper shoe of the die set. Such nonaxial forces could result from clearances and distortions in the moving parts.

As comparatively large clearances exist between the moving ram and its guide, guidepins are included in the die set to ensure maintenance of the proper relationship between the upper and lower die elements.

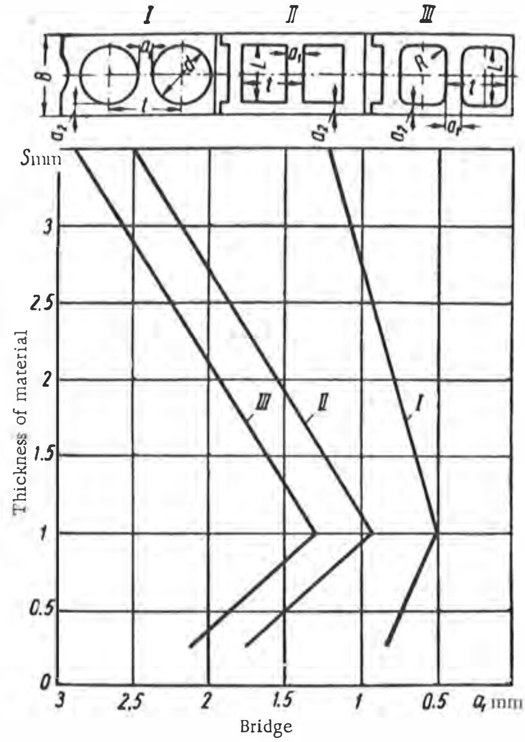


FIGURE 11. Determination of the width of bridges a_1

The dimensions of the die sets used in watch production are standardized (Table 2).

The main working parts of a blanking die are the die and the punch.

Dies can be made either with a cylindrical portion beyond the cutting edge of the die, or with an angular clearance starting right from the cutting edge (Figure 12).

Dies with a cylindrical portion as distinct from dies with an angular clearance only, preserve their size after regrinding of the face. The clearance between punch and die does not change in such dies. The cutting edge of dies with a cylindrical portion is stronger than that of the other type, but a larger force is required for the ejection of blanks. The relieved section below the cylindrical portion of these dies may take many forms and has practically no influence on the blanking process.

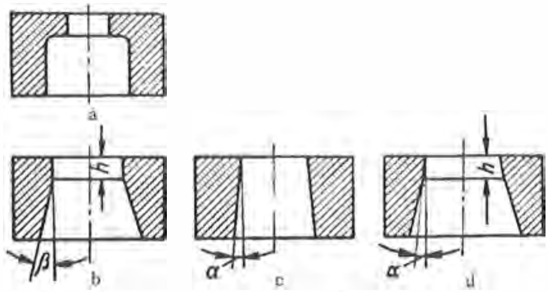
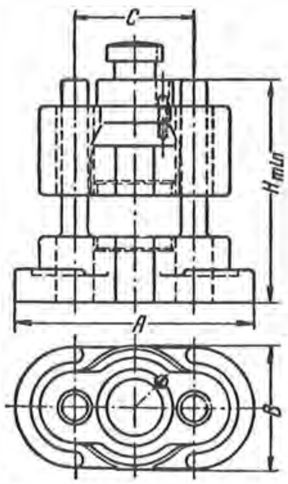


FIGURE 12. Blanking dies:

a and b–dies with a cylindrical portion; c and d–dies with an angular clearance only, starting at the cutting edge.

TABLE 2

Dimensions of model Sh-01 die sets used in watch production, mm



No. of die set	Die-set dimensions				Limiting-blank diameter
	A	B	C	H_{min}	
0	110	55	55	105	10
1	135	70	70	130	15
2	160	85	90	150	25
3	190	95	110	175	35
4	235	130	140	190	50
5	280	160	170	205	65
6	330	180	200	220	85

Dies of the above type are used for blanking precision parts and when the blanked parts have to be pressed back into the strip. The width of the cylindrical portion is usually made equal to the thickness of 2 to 5 parts.

The wider the cylindrical part (within certain limits), the more regrindings the die can bear, and the higher its rigidity.

Dies with angular clearance up to their cutting edge do not retain the blanked parts and therefore no additional force is required for their ejection.

However, because regrinding changes their dimensions, they are not suitable for blanking accurate parts. The rigidity of such dies is less than that of dies with a cylindrical portion and they require more frequent regrindings. Dies with a full angular clearance are also more difficult to manufacture. In order to overcome some of the above drawbacks, die openings are sometimes provided with a double angular clearance (see Figure 12, d). The clearance in the working part of the opening has a slope of 0°15' to 0°30', while in the nonworking part the slope is 2° to 5°.

The die blocks have holes for fastening to the die shoes, and for the mounting of stops, strippers, guides, and other die components (Figure 13).

Punches are subject to high crushing, bending and also tensile stresses. In order that the punch be stable in operation, it should be as short as possible, or be mounted in a guide. If the punch is not guided, holes to be punched should not have a diameter smaller than the stock thickness. Guided punches can make holes of diameters down to 0.5 — 0.75 of the stock thickness.

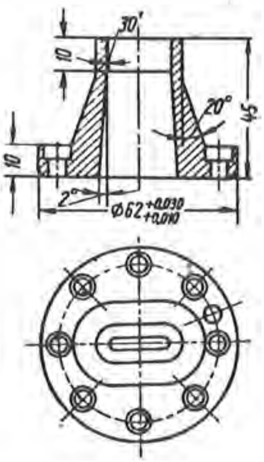


FIGURE 13. Punch and die of a compound blanking die

Examples of punch mountings are shown in Figure 14.

Dies and punches are generally made from high-carbon or chromium tool steels. However, dies and punches used in the production of watch components are frequently made of BK6, BK8, and other hard-alloy grades (Figure 15).

The durability of dies having cutting parts made from hard alloys is 10-15 times as high as that of dies and punches made of tool steel.

A blanking die for an irregularly shaped part is shown in Figure 16.

To facilitate the manufacture of these dies, they are built-up from sections, with the joints chosen in such a way that all parts of the contour can be machined. Sectional dies are held together by rings. The rigidity of sectional dies is somewhat lower than that of solid dies and the considerable stresses sometimes produce dents at the joints.

In order to increase the durability of the die set it is so adjusted that the punch penetrates into the die to a depth not exceeding the thickness of the part.

Strippers. When parts are blanked or holes pierced, the punch penetrates the entire stock thickness and in order to pull it out of the strip, or to remove the strip from the punch, a force of the order of 10 to 15 % of the blanking force must be applied. Die components used for this purpose are called strippers.

The strippers in simple blanking dies are permanently attached to the die and are stationary. The stock passes freely between the stripper and die and the strippers also serve to guide the stock (Figure 17).

The strippers in compound blanking dies are mounted separately from the lower die (see Figure 20).

Types of blanking dies. Blanking dies are classified, according to their principle of action, as single-action dies, progressive dies, and compound dies.

S i n g l e - a c t i o n d i e s are used for blanking the external contours of parts, and the blanked parts are ejected through the die hole.

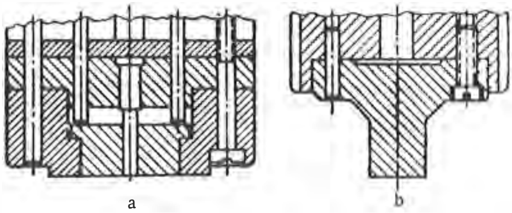


FIGURE 14. Punch mounting:

a–with additional guiding in the knock-out; b–without additional guiding.

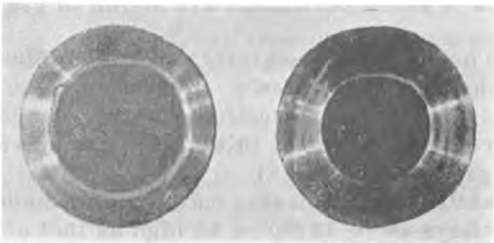


FIGURE 15. Hard-alloy dies

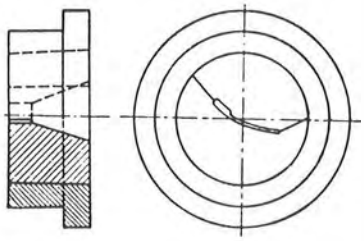


FIGURE 16. Sectional die

The design and dimensions of the model Sh-02 blanking die are shown in Figure 17. The stripper (2) is fastened to the die (3). The stock guides (6) are located between the punch and the stripper. The die block, with the parts fastened to it, is mounted in the recess in the lower (die) shoe by pins (4) and two screws (5).

The punch (7) is mounted in the recess of the upper (punch) shoe by the screws and pins (8).

The upper shoe contains two hardened steel bushings (9) for the guidepins. The bushings increase the service life of the die and its accuracy as otherwise the holes in the cast-iron shoe would be rapidly worn out and the die would lose its accuracy.

The shank (10) is screwed into the upper shoe, and is secured by the stud (1).

P r o g r e s s i v e d i e s for blanking parts with holes. These dies are used for blanking parts in which accurate location of the hole relative to the external contour is not required, and where the width of the bridge between the external contour and the hole is small. The use of a compound die (see below) for such a part is not expedient, since the punch and die will have weakened cross sections and will therefore be unreliable. Figure 18 shows a two-row strip layout for alarm-clock pawls, which are blanked in the following sequence.

First-operation – piercing the hole in the first part; second operation – blanking the contour of the first part; third operation – piercing the hole in the second part; fourth operation – blanking the contour of the second part.

This die operates with two side cutters. A general view of the die is shown in Figure 19.

The die has no guidepins, punches being guided by the stripper (1) which is mounted on the die (2). In order to increase the durability of the die, hardened bushings (3) are pressed into it. The piercing and blanking punches (4) and (5) and the side cutters (6) are fastened to the upper shoe. The punches never leave the guiding stripper (1) during the operation of the die.

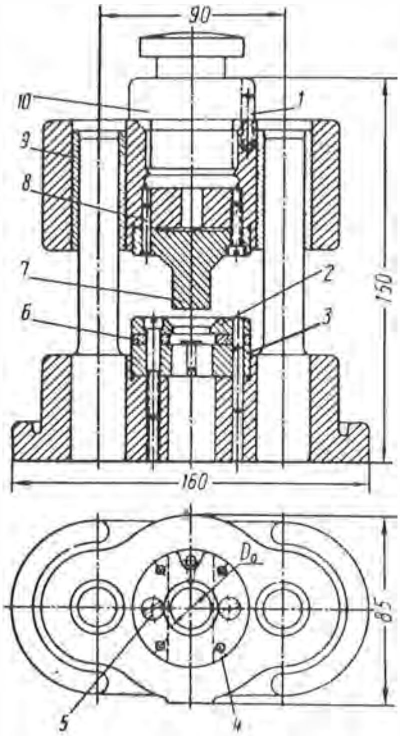


FIGURE 17. Model Sh-02 blanking die with fixed-type lower stripper

Progressive dies are of a much simpler design than are compound dies.

Compound dies are used for blanking parts with windows and holes where an accurate mutual location of the holes and the contour is required.

Compound dies are widely used in watch manufacture, as they make it possible to blank parts to a high degree of accuracy (0.02 mm). Their shortcoming lies in the complexity of their design and manufacture.

A schematic drawing of the model Sh-04 compound die for blanking a round part with a hole is shown in Figure 20.

When the upper die is lowered, the stock is pressed onto the lower die. The spring stripper (4) descends simultaneously with the upper die, the blanking punch (5) and the die (3) blank the part, and the knock-out (6) is pushed back. At the same time the piercing punch (2), cooperating with the hole in the blanking punch (5) which constitutes a die, pierces a hole in the part. When the upper die is lifted, the stripper (4) removes the stock from the blanking punch (5), while the knock-out (6), actuated by the push pin (1) and the spring (7), ejects the blanked part from the die (3) and forces it back into the strip.

The model Sh-06 compound die for blanking brass wheels is shown in Figure 21.

The blanking punch (6-7) is mounted in the lower shoe of this die and serves also as piercing die for both the sector windows and the central hole. The punch is composed of the contour punch (Figure 22, a) and the core (Figure 22, b), clamped together by the ring (5) (Figure 21). The stock stripper (4) is also mounted in the lower shoe.

The die (3) for blanking the external contour of the part, and the punch (2) for blanking the sector windows, are mounted in the upper shoe. The punch (2) consists of five sectors (Figure 23). The punch (1) (Figure 21) for piercing the central hole, and the knock-out (8) for pressing the part back into the strip, are also mounted in the upper shoe.

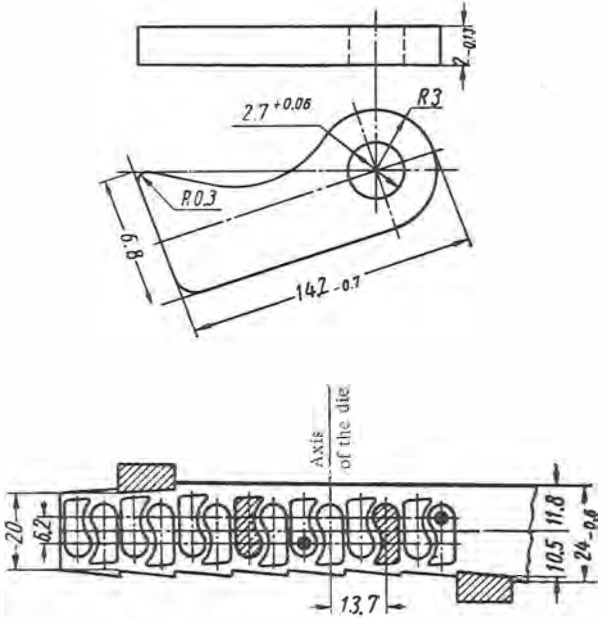


FIGURE 18. Strip layout of alarm-clock pawls for stamping on a progressive die

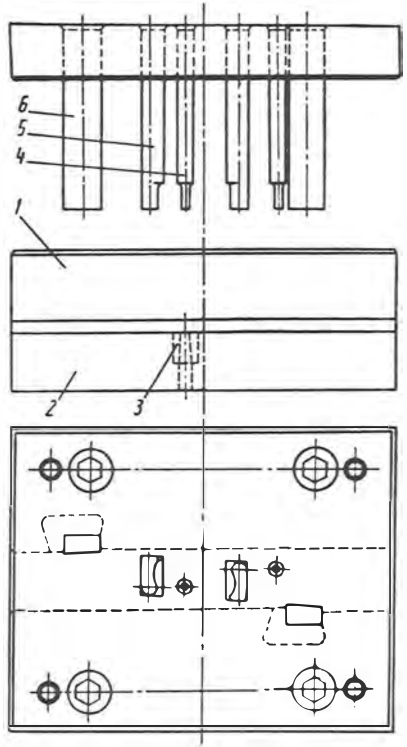


FIGURE 19. General view of a progressive die

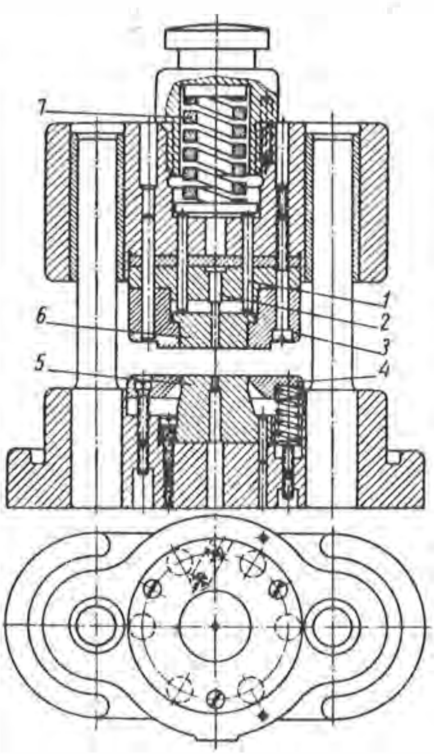


FIGURE 20. Sh-04 compound blanking die

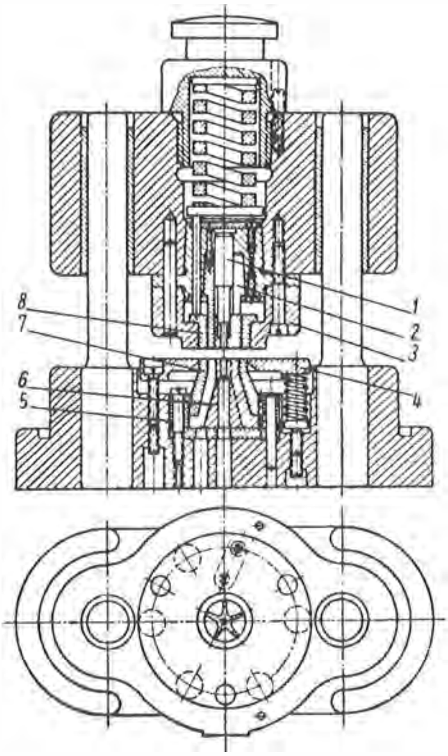


FIGURE 21. Sh-06 compound die for blanking wheels with tapering spokes

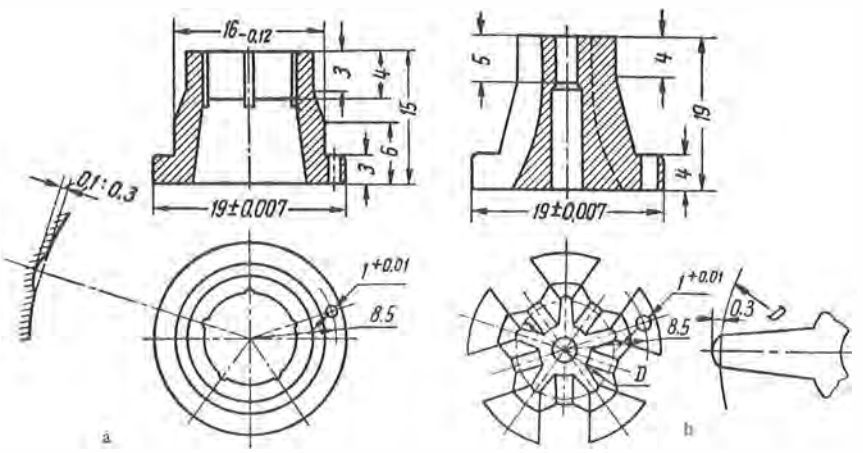


FIGURE 22. Lower punch:

a–contour punch; b–punch core.

The knock-out (8) (Figure 24) consists of the knock-out proper (Figure 24, a), and the star-shaped core (Figure 24, b).

The working parts of the die set are standardized. The dimensions of the upper and lower punches mounted in the die set No. 1 are given in Figure 22 – 24 (see Table 2).

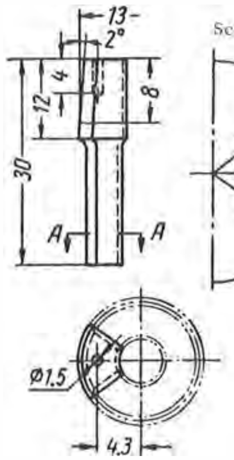
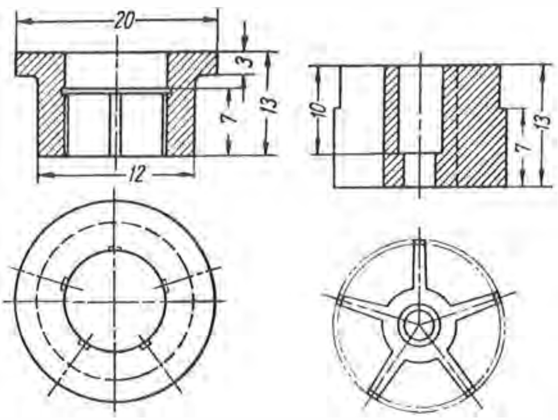


FIGURE 23. Upper punch for punching windows



a b

FIGURE 24. Knock-out of a sectional die: a–knock-out proper; b–core.

The stamping die operates as follows: when the upper shoe is lowered, the punch (6 – 7) penetrates into the die (3) and blanks the part. The stripper (4) goes down. The knock-out (8) is forced up and compresses the spring through a pin and washer. Simultaneously, the punches (1) and (2) produce the sector windows and the central hole. Slugs from the holes drop through a hole in the lower shoe and the bolster plate into a box. When the upper shoe returns, the blanked part is ejected by the knock-out (8), the stock is removed from the punch (6 – 7) by the stripper (4), and the part is forced back into the strip.

Parts punched by this method have no rough edges and do not require any additional straightening. They need only be pressed out of the strip, a very simple operation. For stable operation all parts of the die set should have proper fits and should be centered.

Hardened steel disks are placed between the contact faces of the cast-iron shoes and the die block in order to protect the shoe against local denting.

Piercing dies are a variant of the blanking dies. They are used for piercing holes in blanked parts located in the die by their external contour.

A piercing die for piercing a central hole in gears located according to their external diameter is shown in Figure 25.

The gear is inserted into the conical part of the centering nest (6). The die (8) is mounted on the upper shoe and the punch (5) in the punch holder (1). The centering nest (6) is free to slide on the punch holder (1) and is held by three springs (3). The part to be pierced is put into the centering nest (6).

At the beginning the descending die (8) presses the part against the stripper (7) which is thereby forced down, compressing the spring (4). The punch (5) then pierces (or calibrates) the hole. The slugs pass through the hole in the die (8) and in the upper shoe and are ejected. The centering nest (6) is also lowered, compressing the springs (3).

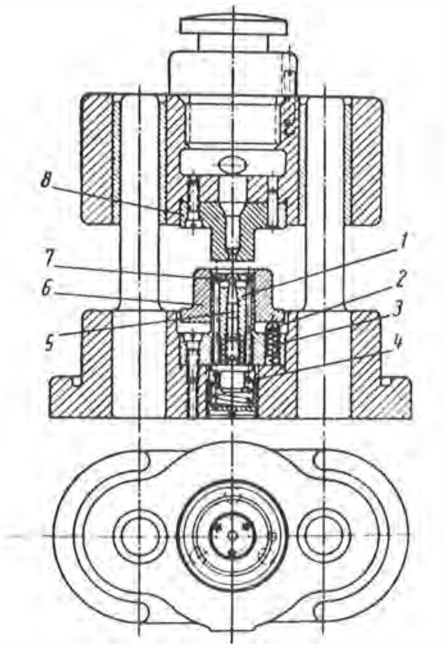


FIGURE 25. Piercing die for piercing a central hole in gears

After the hole has been pierced, the upper shoe retracts while the centering nest (6) and the stripper (7) return to their original positions under the action of their respective springs. The part is removed with the aid of pincers. Having a run-out of not more than 0.015 mm, the central hole pierced by this die is more concentric than those made by the formerly used method of drilling or boring on a machine with the wheel clamped in a collet.

DINKING, SHAVING, AND BENDING

Dinking is a process for blanking parts from mica, leather, cardboard and other thin nonmetallic materials.

The dinking process consists in cutting the material with a hollow punch having a closed contour. The die is constituted by a smooth lead or mild-steel plate. The punch is hardened to $R_C = 52$ to 56 and the marks left by the punch on the surface of the die are removed at certain fixed time intervals.

Typical punch designs for dinking disks and washers are shown in Figure 26. The punch shear angle α is 15 to 18°.

Shaving. Parts blanked from stock more than 0.5 mm thick will have rough edges and burrs.

Most watch parts are required to have a smoothly finished shear surface (class 7-8) perpendicular to the main plane and the parts are shaved after blanking to achieve this finish. Shaving allowances are given in Table 3. These allowances should be increased by 50-60% at sharp angles and sharp transitions where burrs are liable to attain dimensions as large as 50% of the blank thickness. The allowances are also increased by 0.5 to 0.8% of the major blank dimension when this dimension is larger than 20 mm.

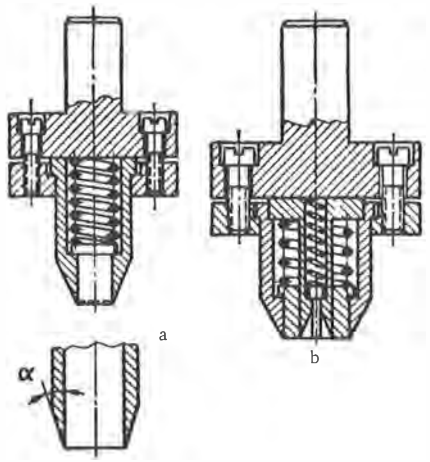


FIGURE 26. Dinking dies: a–for disks; b–for washers

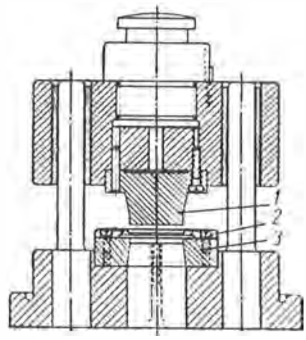


FIGURE 27. Sh-03 shaving die

Parts may be shaved on both their external and their internal contours. The part to be shaved in the die set in Figure 27 is placed on the die (3) and properly located by the nest (2). When the punch (1) is lowered, the part is forced through the die opening whose cutting edges shear the metal along the desired contour.

TABLE 3

Shaving allowances for 20 mm-diameter blanks (total for both sides)

Part thickness	Material					
	Mild steel and brass		Steel of average hardness		Hard steel	
	min	max	min	max	min	max
0.5–1.5	0.10	0.15	0.15	0.20	0.15	0.25
1.6–3	0.15	0.20	0.20	0.25	0.20	0.30
3.1–4	0.20	0.25	0.25	0.30	0.25	0.35
4.2–5.5	0.25	0.30	0.30	0.35	0.30	0.40

In order that the allowance be uniformly removed, the nest (2) must be accurately positioned relative to the die contour, and it is therefore punched in situ by the shaving-die punch itself after which the opening is enlarged by the value of the allowance, and chamfered.

In watch production it is frequently necessary to blank and shave parts whose thickness is 2-5 times their width or diameter. In such cases the blanking allowance is increased, and the blank is shaved on a die set having a punch larger than the die opening.

In this type of shaving die the punch does not penetrate into the die, and each part is ejected from the die by the following part. A surface thus shaved has a better finish, and the part is flatter, but the shaving force required is much larger than that required in shaving by the usual method. Springs of stop watches (see Figure 10) are shaved by this method.

When the contour of a part serves as the base for subsequent operations parts may be shaved two or three times. Each subsequent shaving operation removes a smaller and more even layer and the dies used in the final shaving must therefore be much more rigid than the first shaving die.

Multiple shaving produces more uniform dimensions and a better surface quality. The parts must be shaved in the same direction in which they were blanked, as otherwise burrs will appear on the edges.

Thin steel parts are frequently sized instead of being shaved and this process produces a class 9 or 10 finish on the lateral surfaces. In sizing, the working edges of the die are blunt, and as a result the part increases in thickness (Figure 28).

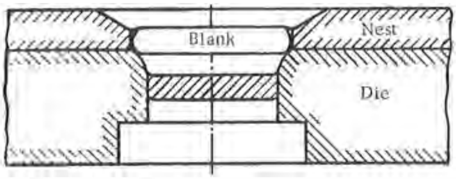


FIGURE 28. Schematic representation of the sizing process

The shaving force P is calculated from the formula

$$P = kl \cdot a\sigma_s ,$$

where l = perimeter, mm;

a = allowance per side, mm;

σ_s = shear strength, kg/mm^2;

k = coefficient allowing for the ejection force Q and the shaving depth h.

For steel with an ultimate strength $\sigma_u \geqslant 90$ kg/mm^2, k = 1.5 to 1.6; for brass with σ_u up to 60 kg/mm^2 k = 1.2 for a stock thickness of 1 mm.

Example. It is required to determine the force P necessary for shaving a watch plate 38 mm in diameter and 3.2 mm thick. Table 3, after adding 0.8%D, recommends an allowance of 0.52 mm. Further given are σ_s = 38 kg/mm^2 and k = 1.4. We therefore obtain P = 1.43×3.14×38×0.52*×38 = 3.4 t.

The force P required for sizing is higher by 30% than that required for shaving and a minimum allowance of 0.03 to 0.08 mm per side is fixed.

----

* [The value 0.52, taken from Table 3, constitutes the total allowance, i.e., 2a. As, however, the above formula operates with the allowance on one side only, i.e. with a, it seems that 0.26 should be substituted for 0.52, which of course would reduce P to 1.7 t.]

The same die sets are used for shaving dies as are used for blanking dies (Figure 27).

Dies with a fixed nest are used for shaving parts of thickness up to 1 mm. Thicker parts are shaved on dies with swing-out nests (Figure 29).

The nest is first swung clear of the working zone of the die set and the die is carefully cleaned, removing all chips. The part to be shaved is then inserted into the nest. The adjustment of the die set (the positioning of the punch relative to the die) is much easier with swing-out nests. On the other hand, it should be kept in mind that the positioning accuracy of swing-out nests is inferior to that of fixed nests and that, with swing-out nests, the shaving action may be nonuniform. Accidental notching of swing-out nests is a possibility to be reckoned with.

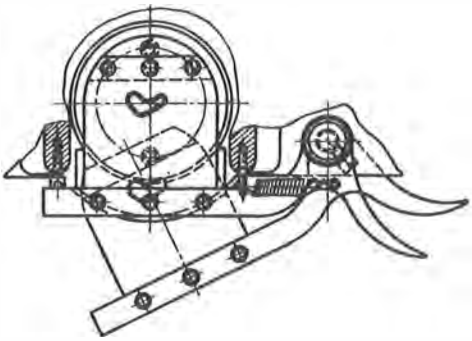


FIGURE 29. Swing-out nest for a shaving die

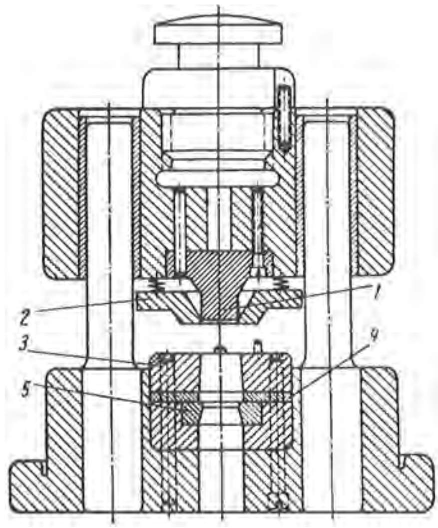


FIGURE 30. Combination blanking-shaving die

It should be mentioned that, according to safety rules, parts may be fed into fixed nests with pincers only.

Combination blanking-shaving dies are now widely used in watch production.

The design of such a combination die for plates and bridges is shown in Figure 30. The upper shoe of the die set carries the punch (1) and the stripper (2) and on the lower shoe are mounted the blanking die (3), the pads (4), and the shaving die (5).

The first time the punch (1) descends, the strip is pressed against the die block by the stripper (2), a part is blanked, and remains in the die. The second strike of the punch blanks another part and the first part is pushed into the hole in the pads (4). During the third blanking the first part is shaved by the die (5). The shavings are removed by a jet of compressed air through a lateral window between the pads. The two dies, together with the pads, are a single assembly and are mounted on the lower shoe.

A shortcoming of these dies is that the whole set has to be dismantled for regrinding. In other models the dies and punches are ground in the shoes. Generally, standard crank presses are used for shaving operations. Precision parts, in particular springs of the type shown in Figure 10, are shaved on vibration presses.

Bending. When a part is bent, the external fibers of the metal are stretched and, if the bending radius is small and the part thickness large, failure occurs in the external fibers.

The values of the smallest bending radius permissible depends on the properties of the metal, the strip thickness and the relative directions of the axis of the bend and the grain. The value of r is determined from the formula

$$r = k \cdot s,$$

where s = strip thickness, mm;
k = a factor depending on the material, and having the following values for various metals:

Material	Soft brass	Semihard brass	Soft steel	Semihard steel	Stainless steel
k	0.25	0.35	0.35	0.6	2

Assuming that the length of the neutral axis remains unchanged in bending, and that the inside fibers are compressed and the outside fibers extended, the blank length (Figure 31) is determined from the following formula:

$$L = l_1 + l_2 + \frac{\pi \alpha^\circ}{180}(r + n \cdot s),$$

where l_1 and l_2 = lengths of the straight sections, mm;
r = bending radius, mm;
s = stock thickness, mm;
α = bend angle, degrees;
n = a coefficient depending on ratio $\frac{r}{s}$, having the following values:

$\frac{r}{s}$	0.1	0.25	0.5	1	2	4	5
n	0.18	0.26	0.33	0.39	0.44	0.47	0.50

Elastic deformation is always present in bending, and the part tends to "spring back", that is, partially returns to its original shape. The actual final bend angle is therefore smaller than the die bend angle.

The magnitude of the spring-back depends on many factors and it is frequently necessary to determine the punch and die angles of bending dies empirically. Figure 32 is a nomogram of the spring-back angle $\Delta\alpha^\circ$ as a function of the bend angle and the ratio $\frac{r}{s}$. The disposition of the axis of the bend relative to the grain of the material is very important.

As mentioned earlier, rolled materials, i.e. materials having a definite direction of grain, should not be bent about an axis parallel to this direction as the extended outside fibers are liable to fail. The angle between the axis

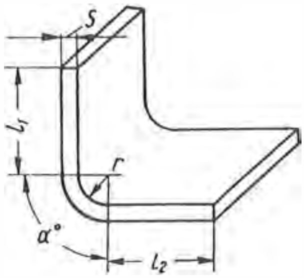


FIGURE 31. Bent plate

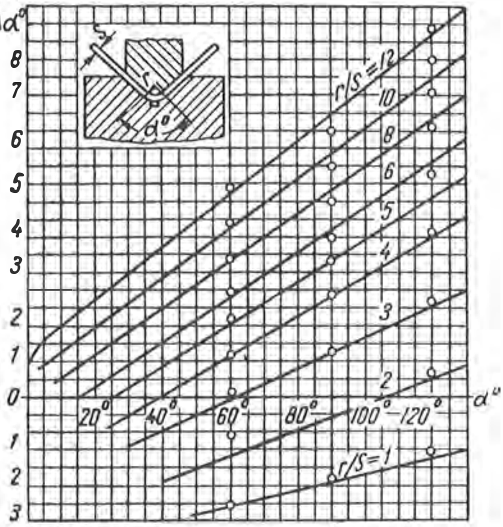


FIGURE 32. Dependence of the spring-back Δα on the ratio r/S

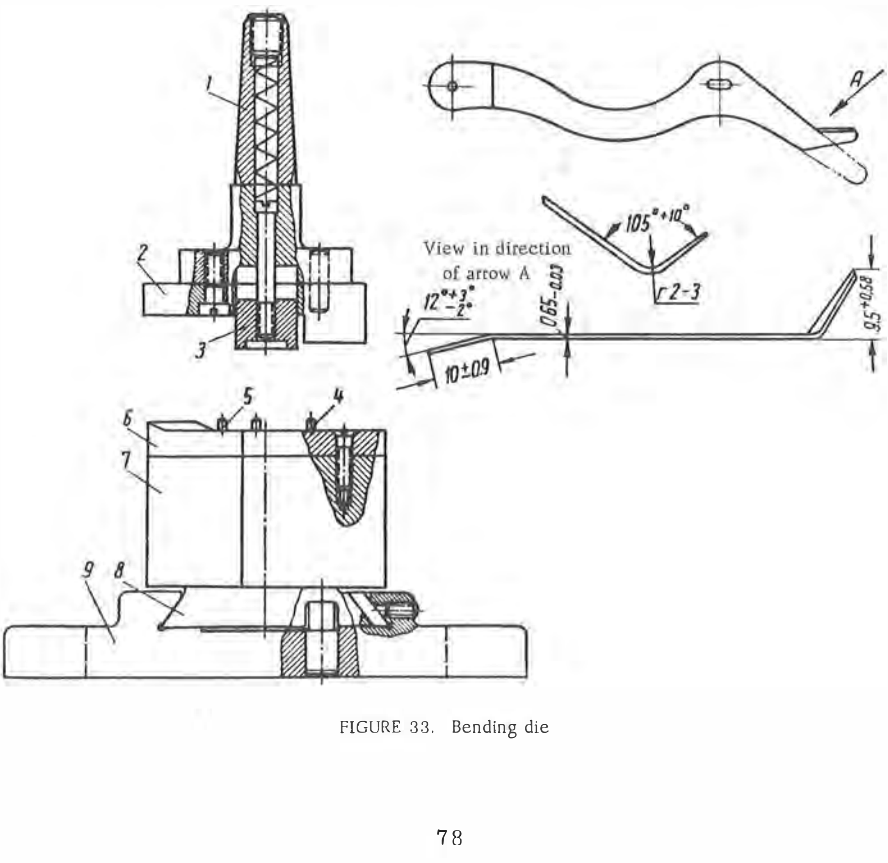


FIGURE 33. Bending die

of bending and the direction of the grain should therefore preferably be 90°, but should not be reduced below 30°.

Bending dies are relatively simple in design. The shapes of the punches and dies correspond to that of the part to be bent, allowing for spring-back. Open-type dies are used for simple bending operations, while more complex operations are performed on dies provided with knock-outs and special blank holders.

The design of a bending die for alarm-clock detents is shown in Figure 33. Both ends of the detent are bent simultaneously. The die (6) with the guide pins (4) and (5) is mounted on the support (7). The support can move with the slide (8) in the base (9). The punch (2) and the pressure pad (3) are fastened to the shank (1). When the press ram descends, the pad (3) presses the part against the die face. As the punch (2) continues to descend, the right-hand end of the detent is bent by 105°. The bending radius r is about 2.5 mm, or $4s$.

DRAWING

Hollow parts are drawn from flat blanks on single-action or double-action presses.

Drawing can be defined as a process in which a punch forces a flat blank into a die hole and causes it to assume the shape of the punch (Figure 34).

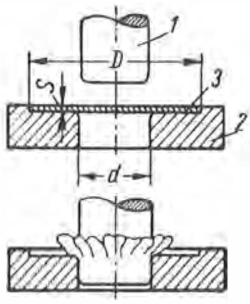


FIGURE 34. Schematic diagram of the drawing process

1-punch; 2-die; 3-blank.

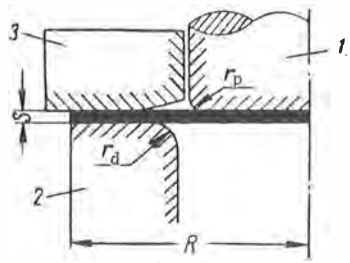


FIGURE 35 Schematic diagram of drawing with a blank holder

1-punch; 2-die; 3-blank holder.

Drawing operations are of two types: 1) drawing without changing the initial stock thickness (the thickness of the walls and of the bottom of the product are equal to the blank thickness); 2) drawing with a reduction in the stock thickness (the wall thickness of the product is smaller than the blank thickness). If the difference between the diameter of the product and that of the blank is small, drawing is performed without using a blank holder. If the difference in diameters is considerable, a blank holder is used (Figure 35), as otherwise wrinkles may form (Figure 34). A blank holder is used in all cases where the blank thickness does not exceed 1/70 of its diameter. If the thickness of the blank is larger than 1/50 of its diameter, a blank holder is not necessary. If the thickness is somewhere in between, either system can be used. The press force required increases when a blank holder is used.

Deep shells are drawn in two, three or more stages with intermediate annealings to eliminate the work-hardening effect. Alarm-clock cases and air- and seaborne watch cases are examples of drawn watch parts.

Blank dimensions. Drawing does not change the volume of the metal. If the wall thickness of the drawn product is the same as that of the blank, the blank area F_1 will be equal to the surface area F_2 of the drawn product. If the height of the product does not exceed half its diameter and its wall is not larger than 1 mm, F_2 will be the external surface of the product*.

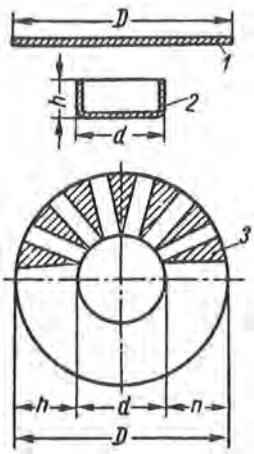


FIGURE 36. Development of a hollow cylinder:

1-blank; 2-product; 3-development.

The diameter D of the circular blank from which a hollow cylinder of height h and diameter d (Figure 36) is to be drawn is found from the relationship $\frac{\pi D^2}{4} = \frac{\pi d^2}{4} + \pi dh$; we obtain: $D = \sqrt{d(d+4h)}$.

An allowance of 3 to 5% is added for trimming the edges which, after drawing, will be uneven.

When a complex part is drawn in several stages, the dimensions of the blank are either computed or experimentally determined.

Figure 37 gives the formulas for calculating the blank diameter for various drawn shapes.

Number of stages in drawing. Deep shells cannot be produced in one single draw from a flat blank as the extensive deformation involved would cause a failure. Deep shells are therefore drawn in several stages, the depth being increased in each stage.

The ratio of product diameter to blank diameter for each draw is expressed as the draw coefficient:

$$m_1 = \frac{d_1}{D}; \quad m_2 = \frac{d_2}{d_1}; \quad m_n = \frac{d_n}{d_{n-1}},$$

where D = the blank diameter;
m_1, m_2, m_n = draw coefficients;
d_1, d_2, d_{n-1} = diameters obtained in the successive draws;
d_n = diameter of the final product.

The draw coefficient m depends on the technological properties of the material as determined by the Erichsen test, on its surface condition and thickness, on the drawing method used (with or without a blank holder), on the product shape, etc.

Empirical average values of draw coefficients for cylindrical products are given in Table 4.

The higher values given in each case should be used for stock not thicker than 1.5 mm and drawn at high speed while the lower values are meant for thicker stock, drawn at lower speeds.

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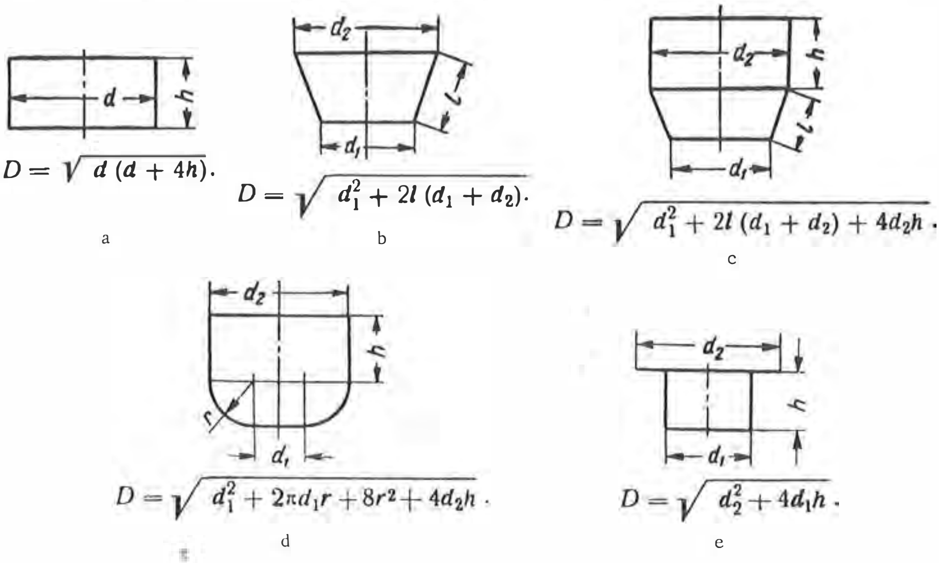
* For drawing irregularly shaped products of complex shape, the calculations given in V. P. Romanovskii's book "Spravochnik po kholodnoi shtampovke" (Handbook of Cold Stamping) Mashgiz, 1954, will be useful.

The metal is work-hardened during drawing and the work hardening must be eliminated before the subsequent draw. The parts are therefore annealed and pickled, after which the scale is removed by washing.



a: $$D = \sqrt{d(d+4h)}.$$

b: $$D = \sqrt{d_1^2 + 2l(d_1 + d_2)}.$$

c: $$D = \sqrt{d_1^2 + 2l(d_1 + d_2) + 4d_2h}.$$

d: $$D = \sqrt{d_1^2 + 2\pi d_1 r + 8r^2 + 4d_2h}.$$

e: $$D = \sqrt{d_2^2 + 4d_1h}.$$

FIGURE 37. Calculation of blank diameters for drawing operations

TABLE 4

Draw coefficients

Material	First draw, m_1	Subsequent draws, m_n
Brass L62, tombac	0.50—0.54	0.70—0.75
Mild steel	0.52—0.60	0.72—0.80

Clearances between punch and die. The magnitude of the clearance between the punch and the die depends on the blank thickness and on the type of drawing (with or without a decrease in the wall thickness). When the thickness of the material is not changed a clearance somewhat larger than the stock thickness is specified, so as to reduce the friction between the stock and the die walls. Too large a clearance leads to the appearance of wrinkles and too small a clearance will lead to reduced wall thickness.

The clearance for the case of unchanged thickness is determined from the formula

$$l = A \cdot s,$$

where A = coefficient;

s = stock thickness.

A is taken as 1.25 for $s < 1$ mm, and 1.1 for $s > 1$ mm.

Radii of the die and punch. The radii of curvature of the dies and punches are of great importance in drawing. Small radii produce high stresses and can lead to tearing, while large radii may cause the metal to wrinkle.

The radius of curvature of the die edge for the first draw is usually ten times the stock thickness for steel and six times the stock thickness for brass. In subsequent draws, the edge radius is reduced to 60-80% of the first-draw edge radius, but should not be less than $3s$. The punch radii are generally equal to the die radii.

The punch radius for the final operation must, of course, be equal to the desired product radius.

Lubrication. Friction in drawing operations, between punch, stock and die, is considerable. This friction is reduced by lubricating the blanks with engine oil, vaseline, emulsions, or powdered-graphite suspension, etc.

Drawing force and blank-holder pressure. The drawing force is determined from the formula

$P_1 = \pi d_1 \cdot s \cdot \sigma_u n_1$ for the first operation;

$P_2 = \pi d_2 \cdot s \cdot \sigma_u n_2$ for the second and subsequent operations,

where d_1, d_2 = the diameters of the drawn part after the first and second operations, respectively;

n_1, n_2 = correction factors depending on the ratio $\frac{s}{D}$.

The values of n_1 and n_2 are usually between 0.6 and 0.8.

The blank-holder force is determined from the formula

$$Q = qF,$$

where Q = the holding force, kg;

q = the blank-holder pressure, kg/mm^2;

F = the blank-holder area, mm^2.

If the holding force is insufficient, wrinkles are formed on the blanks. If it is too large, the blank may tear.

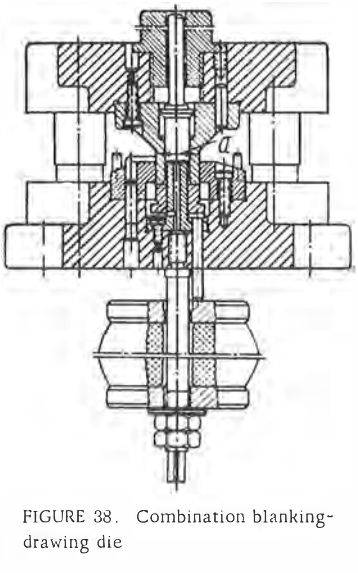


FIGURE 38. Combination blanking-drawing die

The value of q can be taken as 0.15 to 0.20 kg/mm^2 for brass, and 0.20 – 0.30 kg/mm^2 for steel. The total press force is

$$P_n = P + Q.$$

Drawing dies are classified, according to the operations they perform, as first-draw dies, or dies for second, or subsequent draws.

First-draw dies can be either simple or combination dies. A simple die draws a previously punched blank. A combination die (Figure 38) performs both blanking and first-drawing operations.

The die can operate on a single-action press. The blanking punch, a hole in which serves as a drawing die, is fastened to the upper shoe. The blanking die and the drawing punch are mounted on the lower shoe. The die is provided with a rubber cushion for stripping and ejecting the part.

STRAIGHTENING, POINTING (CENTER PUNCHING), EMBOSSING, STAMPING

Straightening. Parts obtained from a blanking operation are usually not completely flat. Such parts can be flattened and smoothed by squeezing them between the punch and die surfaces of a die set. If the surfaces of the punch and die are smooth, the process is called s m o o t h straightening.

If angular slots are milled on the punch and die surfaces in two mutually perpendicular direction, (knurling) pyramids with sharp apices result. A part straightened on such a die bears imprints on its surface and this process is called p o i n t straightening.

The apices of the punch pyramids do not necessarily coincide with those of the die pyramids. Point straightening gives better results than does smooth straightening, and a part subjected to point straightening does not show elastic spring-back. If the apices of the punch and die pyramids are blunted, the depression pattern formed on the surface of the straightened part is of the so-called w a f e r type and is used for thick parts made of soft metals.

A die used in the point straightening of alarm-clock plates is shown in Figure 39. Since straightening imprints are not allowed around the holes in this part, the pyramidal apices have been removed near the holes. The alarm-clock plate is positioned for straightening by means of pins matching the holes in the plate.

Pointing (center punching). A pointing die consists of flat punch and die plates with hardened-steel points pressed into the die and protruding above its surface.

The blank is located in a nest which is either fastened to the die or set on pins mounted on the die.

When the upper shoe of the die set is lowered, the lower face of the punch presses the blank against the upper die face, and the points penetrate into the metal and indent it. These indentations serve for guiding the drill in subsequent operations.

In order to reduce the adherence of metal to the points, they must have a smoothly polished surface. The indentation diameter must be larger than the drill diameter, and the angle of the indenting point must be smaller than the drill-point angle.

The position of the drill in the indentation as a function of the point angle and punching depth is shown in Figure 40.

Figure 40, a shows the position of the drill in an indentation of a diameter smaller than the drill diameter. The point angle is 80° and the drill-point angle is about 120°. Touching, initially, only the rim of the pointing crater, the drill is poorly guided. Figure 40, b shows the position of the drill in an indentation of a diameter larger than the drill diameter. The point angle is 80°, and the drill-point angle is about 120°. The displaced metal is not removed in the subsequent drilling. In this case, the drill is better guided and, if properly ground, will produce accurate holes, both from the dimensional and the positional point of view.

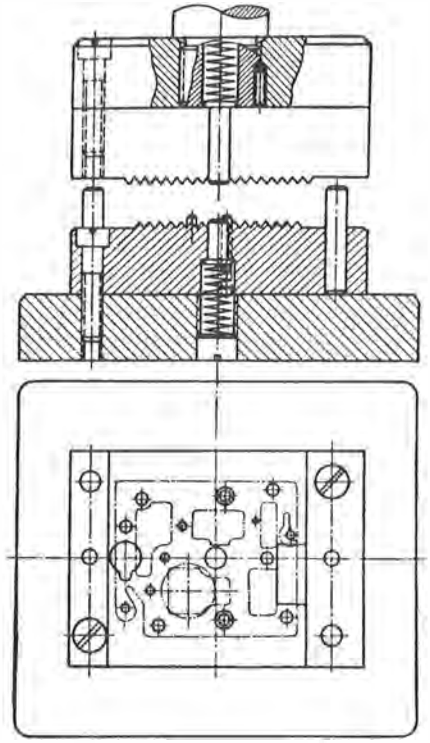


FIGURE 39. Die for point-straightening alarm-clock plates

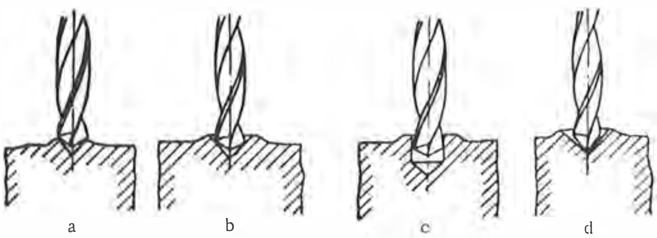


FIGURE 40. Position of the drill in the pointing indentation for different punching depths

Figure 40, c shows an indentation with a cylindrical portion. The drill is initially guided by the cylindrical part, and later by the conical part. This type of center-pointing is recommended for diameters above 1 mm and in parts 3 mm or more thick.

Figure 40, d shows the position of the drill in an indentation with an angle larger than the drill-point angle. In this case the drill contacts the crater with its point, and not with the cutting edges as in the preceding cases. The accuracy of drilled holes is lower with this type of indentation.

The required pointing depth is a function of the diameter of the hole to be drilled.

The points must protrude above the die by 0.3 – 0.5 mm more than their actual desired penetration, in order to ensure that a clearance will always exist between the work and the die face, preventing dangerous "dead" impacting of the press.

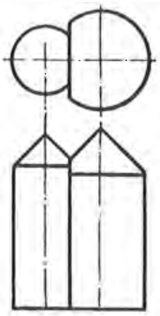


FIGURE 41. Mounting of the pointing punches for small distances between centers

Hole diameters are divided into several groups in order to reduce the variety of pointing-punch sizes. Thus, only three pointing-punch sizes (1, 1.8, and 2.5 mm) are used in drilling holes of diameters 0.50, 0.6, 0.75, 1.10, 1.20, 1.40, 1.80, 2.0 and 2.20 mm.

If the distance between centers for two holes is smaller than the sum of the radii of the pointing punches, flats are machined on both punches (Figure 41).

The design of pointing dies must allow for easy replacement of the pointing punches. Frequent replacement is necessary as metal adheres to the punch point and spreads over the cone surface, distorting the shape of the indentations.

The accuracy of the center punching must not be affected by the frequent dismantling of the die set and by the removal and replacement of the pointing punches themselves.

Repeated grindings of the pointing-punch tips reduces their total length and it eventually becomes insuffficent for forming the indentations. In such cases either the pointing punches are replaced or the die-plate thickness is reduced.

The most widely used pointing-die design is shown in Figure 42.

The hardened-steel die plate (3) is mounted on the lower shoe of the die set and in it are fixed the pointing punches (8). The die plate is connected to the disk (6) by screws (7) and the pin (9). The supporting pins (10), on which the part is placed, are mounted in the disk. The knock-out pins (5), actuated by the knock-out bar (4), pass through the disk (6). The nesting pins (2), which locate the part in the horizontal plane are mounted on the die plate.

The flat-faced punch (1), provided with clearance holes to take the nesting pins (2) is mounted in the upper shoe. When the punch is lowered, the part descends together with the supporting pins and is pressed against the pointing punches. When the punch recedes upward, the supporting pins, being spring-loaded, lift the part off the pointing punches. The part is removed from the nesting pins by a pedal, the knock-out bar (4), and the knock-out pins (5).

It might happen that the longest punches are concentrated on one side of the die, and the shortest punches on the other. The supporting pieces prevent distortion of the part in such cases.

In watch movements the bridges are mounted above plates and the corresponding holes have the same coordinates in both parts. A single die can therefore be designed for pointing the holes first in the plate and then, simultaneously, in the corresponding bridges. This increases the accuracy of hole location in mating parts, and also reduces the number of dies required, althoug such a combination die is more complex than each of a set of separate dies.

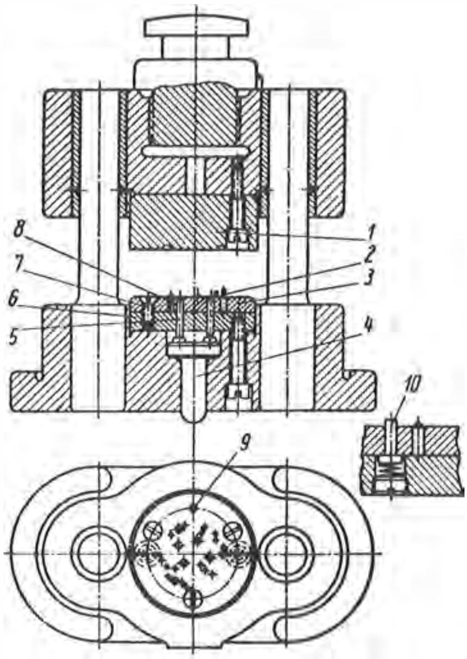


FIGURE 42. Pointing die

Only through-holes can be pointed on bridges by means of such a die. Blind holes necessitate a separate die for each bridge. The accuracy of hole location for pointed holes is 0.03 mm. The positional accuracy obtainable by the use of drilling jigs is 0.05 mm.

The pointing process is very productive and the number of holes pointed is limited only by the part and pointing-punch dimensions. The usual dies can point between 2 and 25 holes.

The shortcoming of hole location by pointing is that the drill operator, using a drill of a given diameter, could conceivably err in his choice of pointing marks corresponding to the given drill, when faced with a large number of pointing marks. Perforated templates (holes 0.05–0.1 mm larger than the hole to be drilled) are used to overcome this disadvantage. Each template is designed for holes of only one diameter.

Embossing and coining*. These operations are used in watch production for obtaining design in relief on the back lid of watches (Figure 43), for producing raised figures and symbols on dials (Figure 44) and for other similar operations.

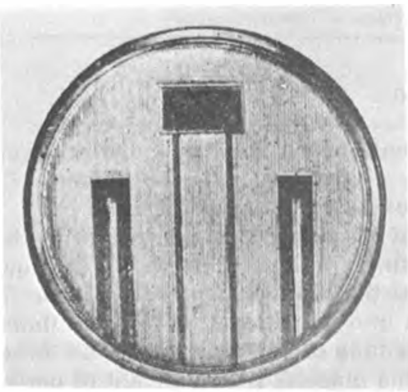


FIGURE 43. Back lid of a pocket-watch case with embossed design

FIGURE 44. Dial with embossed (raised) figures

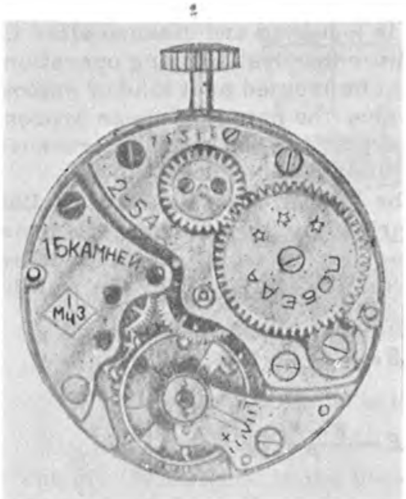


FIGURE 45. Wristwatch mechanism with symbols, figures and inscriptions

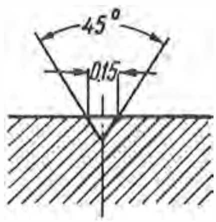


FIGURE 46. Stamping depth of figures and symbols

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* [Russian terminology does not differentiate between embossing and coining dies. As these two terms are frequently confused in American usage, it might be worthwhile to attempt a working definition of the difference between the two: embossing dies have usually the same design on the upper and on the lower die, one being the negative of the other, while coining dies generally present different designs on the upper and lower die, respectively. A special case of the embossing-type of die is the die used to embellish the watch lid shown in Figure 43. Here one die represents the negative of the desired lid surface, while the other die is smooth, serving only as countersupport.]

Stamping. Symbols and figures are often stamped on the bridges and winding wheels of watch movements. Stamping is accompanied by a local plastic deformation. Stamped inscriptions, figures and symbols on the movement of a "Pobeda" wristwatch are shown in Figure 45. The approximate stamping depth is indicated in Figure 46.

SWAGING

In swaging the blank is completely contained in the die under pressure from all sides.

The blanks used are of a shape approximating that of the final part, (cylinders, disks, etc.). The volume of the blank is equal to that of the final part with a small surplus which is required to ensure that the die is completely filled. This surplus goes into the formation of flash (burrs at the parting face of the die) which has to be removed. The blank for the pendant of pocket watches is obtained by cold heading from bar stock and is shown in Figure 47, a, while Figures 47, b and c show the pendant after the first and second swaging stages on a hydraulic press.

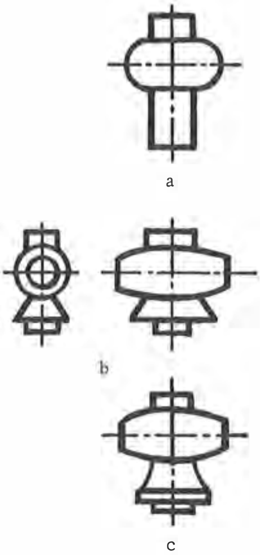

FIGURE 47. Pendant of pocket watches
a–blank; b–after the first operation; c–after the second swaging operation.

The blank is annealed and cleaned after the heading and after the first swaging operation.

Swaging can be treated as a kind of embossing or coining, since the nature of these processes is very similar, as are the working pressures involved (see Table 5).

Metals to be swaged must be ductile. Ductility is characterized by the amount of deformation the metal can endure without fracture. In swaging, the deformation is defined by the relationship

$$E = \frac{H - H_f}{H} 100$$

or

$$E = \frac{F - F_f}{F} 100,$$

where E = the deformation in %;
H and H_f = the initial and final heights of the blank and part, respectively.
F and F_f = the initial and final cross-sectional areas of the blank and part, respectively.

Embossing, coining and swaging operations require considerable pressures (Table 5).

The force P required is determined from the formula

$$P = q \cdot F,$$

where q = the pressure in kg/mm^2;
F = the part surface (in plane) in mm^2.

Swaging operations are performed on powerful knuckle-joint, friction, and hydraulic presses. Swaging of a part is sometimes carried out before the part has been blanked out from the strip (see Figure 48).

TABLE 5

Pressures required for embossing, coining and swaging operations

Type of operation	Ductility E	Pressure kg/mm^2		Surface-quality class	Dimensional accuracy, mm
		brass	steel		
Embossing of a convex-concave design	High	180 250	250-300	8-9	0.02-0.03
Stamping of figures and symbols	Average	100-130	150-280		-
Swaging	"	120-160	180-250	8-9	0.03-0.05
	High	180-250	250-300	-	-

An open-type set without guidepins, used for making a mainspring end piece, is shown in Figure 48. The pin and shoulder are formed in the strip in one press stroke, and the contour is blanked in the next.

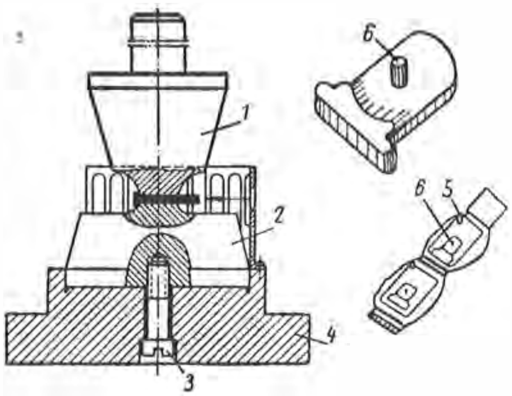

FIGURE 48. Die set for forming mainspring end piece

The die (2) fastened to the lower shoe (4) by the screw (3) has recesses for forming the pins (5) and (6) and the shoulder. The die edges are rounded off for greater durability. The punch (1) is mounted on the press ram.

The metal strip is positioned on the die. The flat end of the punch makes contact with the metal and forces it to flow between its surface and that of the die, and into the die cavities. A relief impression of the part is obtained in the strip. The strip is manually advanced after each stroke. The formed strip is fed to the blanking die.

The forming of chamfers in watch parts can also be classified as a type of swaging. Some watch parts have decorative chamfers on the contour, as do parts of other precision instruments (Figure 49). As the milling of such chamfers is a very expensive process, even using special machines, chamfers are usually formed on stamping dies.

A die set used for forming chamfers on wristwatch bridges is shown in Figure 50. The die (3) is fastened to the lower shoe (1) and has a recess in the shape of the bridge. The depth of the recess is 75% of the bridge thickness and a chamfer with an inverse radius has been produced and carefully polished along the contour of the recess. The punch (5) is mounted on the press ram and is larger than the bridge contour. When the ram descends, the punch presses the metal into the recess and fills it. The excess metal resulting from the chamfer, moves into the punch recess. The chamfered bridge is ejected from the die by the knock-out (2) through the pins (4). After chamfering, the punch-side surface of the bride is cleaned. The chamfering allowance is taken into account in specifying the thickness of the strip used for blanking.

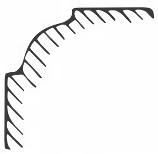

FIGURE 49. Decorative chamfer

Combination stamping. Combination stamping is very effective in mass production. Although combination dies are more complex and require closer attention, the additional investment is justified.

Various operations in watch production, which were formerly performed in separate dies, are now combined into one operation. The blanking and shaving of plates and bridges, case rims, mainspring barrels, etc., are examples.

The winding wheel of the "Pobeda" watch (Figure 51) is made on a combination die which combines five operations: blanking, punching and shaving the square hole, stamping the symbol "Pobeda" and the stars, and straightening.

The combination die for performing these operations is shown in Figure 52, a, The punch (1) (Figure 52, c) for piercing the square hole is stepped. The first step pierces the hole, and the second shaves it. The upper knock-out (2) has the stamping symbols on its face (Figure 52, b).

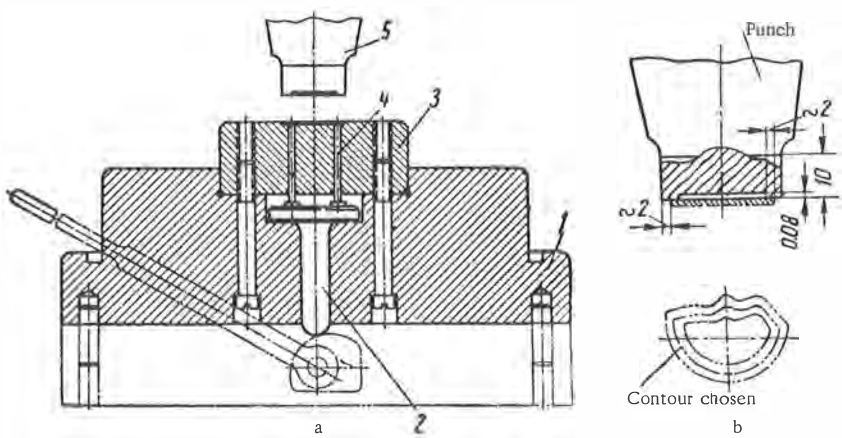

FIGURE 50. Die set for forming chamfers on bridges

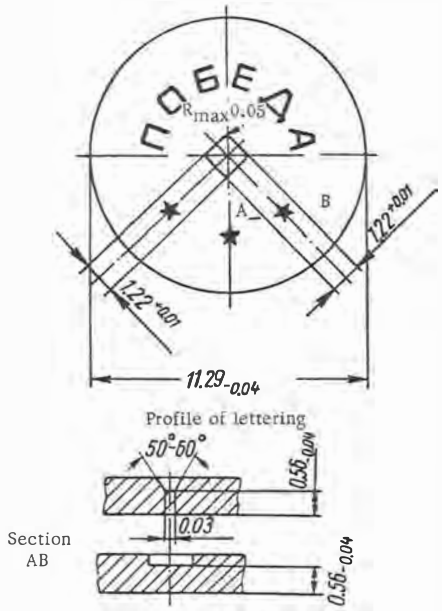

FIGURE 51. Winding wheel of the "Pobeda" wristwatch

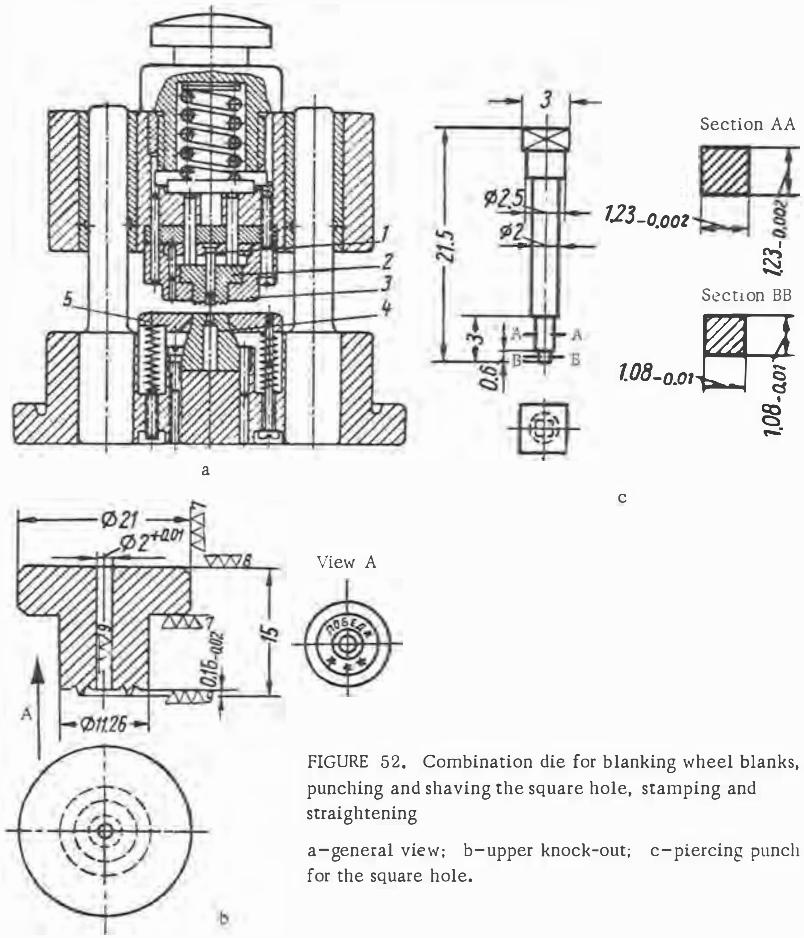

FIGURE 52. Combination die for blanking wheel blanks, punching and shaving the square hole, stamping and straightening

a–general view; b–upper knock-out; c–piercing punch for the square hole.

When the upper shoe of the die set is lowered, the knock-out (2) marks the design, after which the die (3) and punch (4) blank the part. Simultaneously, the square hole is pierced and shaved by the punch (1). The hole in the punch (4) serves as the die for piercing the hole. When the upper shoe is raised, the stripper (5) removes the strip from the punch (4), and the knock-out (2) presses the blank back into the strip simultaneously, by straightening it.

PRESSES

As was mentioned earlier, stamping operations are carried out on presses of various designs.

Presses are classified, according to their working principles, into: crank (single action), vibration, double-action, multi-station, knuckle, friction, and hydraulic presses.

Crank (including eccentric) presses are used for blanking, shaving, bending, stamping, etc., and are the basic equipment of stamping plants.

Figure 53 shows a S-202 6 ton high-speed closed-type crank press with automatic two-roller feed.

The press is driven by an electric motor through a V-belt transmission and a pair of helical gears. The starting clutch is of the sleeve type with rotating wedge; the brake is of the periodic-action band type and adjustable. The controls are hand- or pedal-operated. Mechanical controls are available so that the press cycle may be either continuous or single-stroke.

Technical specifications of the S-202 press

Force at the end of the stroke, tons	6
Working-stroke length (adjustable), mm	From 4 to 40
Number of double strokes per minute	250
Pitch of strip feed, mm	From 0 to 50
Maximum distance between bed and ram, mm	260
Adjustment of the connecting-rod length, mm	50

Shaving operations giving a class 9 or 10 surface quality are performed on D-200 **vibration** presses. A general view of a 6 ton press of this type is shown in Figure 54, and its kinematic scheme is given in Figure 55.

Small parts can be shaved on this press both on their external and internal contours. To achieve more accurate processing, the eccentric B superimposes a reciprocating motion of 90 vibrations per ram stroke over the normal ram motion, controlled by cam A through the rocker arm C.

The press is equipped with a reliable device which prevents double strokes.

A characteristic feature of the shaving process as carried out on this press is that the die executes up to 90 cutting motions for one stroke of the rocker arm, so that the process is similar to scraping. The vibrating ram pushes the part through the die intermittently. A shear surface of class 9 or 10 quality is obtained. The deviation from the nominal contour are of the order of 0.01 to 0.05 mm and up to 5000 parts can be shaved on this press per shift.

Double-action presses are used mainly in drawing. The press has two rams: an outer, or blank holder, ram, and an inner, or plunger, ram,

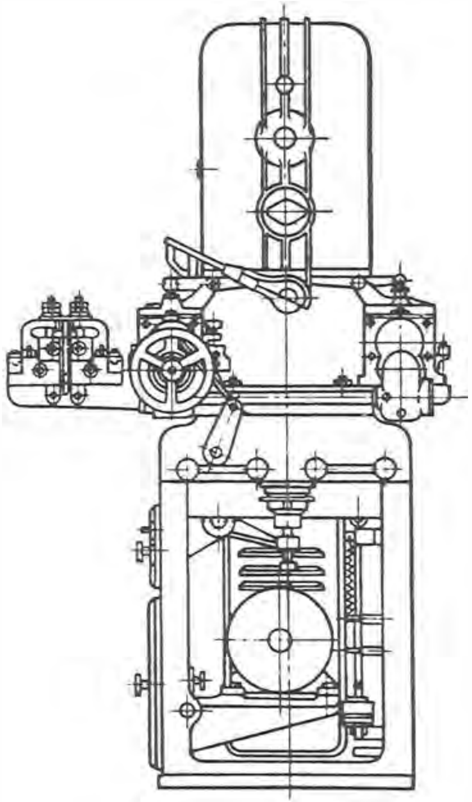

FIGURE 53. S-202 press

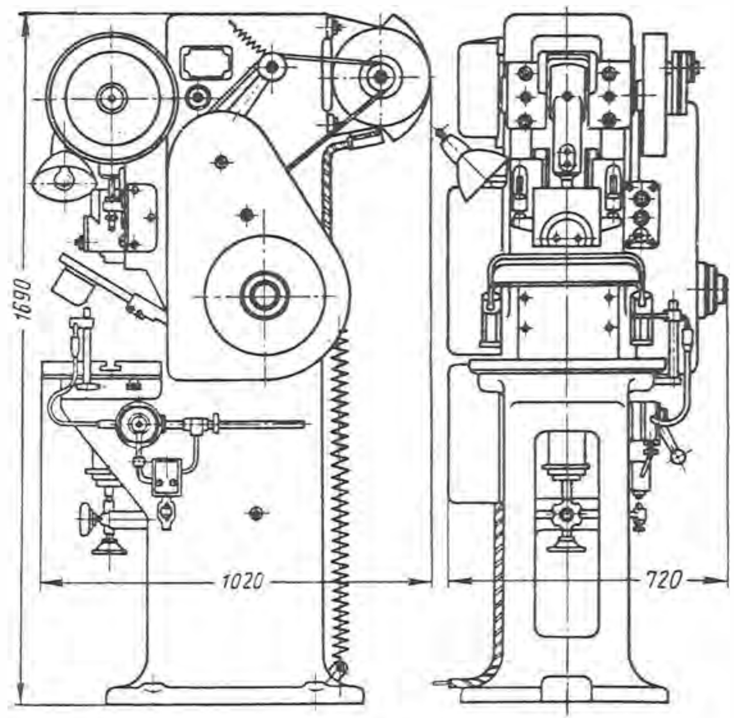

FIGURE 54. D-200 vibration press

carrying the upper die shoe. The motions of the rams are of course coordinated.

The outer ram is actuated by the crankshaft through cams, rollers and rods, or by a pneumatic device.

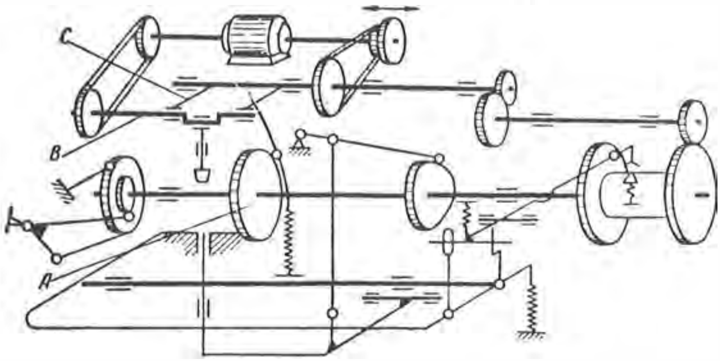

FIGURE 55. Kinematic scheme of the D-200 vibration press

The inner ram is actuated by an ordinary crank mechanism. In drawing, the outer ram clamps the blank before the punch on the inner ram has descended and begun the drawing and holds it until the drawing punch leaves the part. The outer ram is immobilized during the drawing process.

Double-action presses are well suited for combined blanking and drawing. The blanking punch is mounted on the outer ram and serves as blank holder as well.

Multiple-station presses are used in the mass production of parts whose manufacture requires several similar operations, mainly drawing. Finished alarm-clock cases, for instance, can be obtained directly from the strip on such presses. Alarm-clock cases have relatively large dimensions, and were the 5 or 6 stamping operations to be performed on separate presses, considerable floor space and staff would be needed.

Friction presses are used for straightening, stamping, bending and drawing. A press of this type is shown in Figure 56. Two brackets with bearings supporting a shaft with two vertical friction disks are mounted on the press frame. The shaft with the disks is powered by an electric motor through a belt transmission. The shaft can move freely in its axial direction and thus bring either the left-hand or the right-hand disk into contact with a flywheel on a vertical screw. The flywheel is leather-surfaced and the ram, restrained by lateral guides, is raised and lowered by the screw which turns in a nut mounted on the upper part of the frame.

The die set is mounted on the press table.

When the press is started, the shaft carrying the vertical disks rotates and one of the disks is made to contact the flywheel. The flywheel turns the screw in the fixed nut forcing the ram downward. At the beginning, when the flywheel contacts the vertical disk at a small radius, the rotational speed of the flywheel is small. As the flywheel descends with the ram, the radius increases so that the ram has a maximum velocity at the end of the stroke. By this time the flywheel has accumulated a large amount of energy which it transfers to the part to be worked through the screw and the ram. In its lowest position the ram frees a spring which brings the second vertical disk (through a system of levers) into contact with the flywheel. This reverses the direction of rotation of the flywheel and raises the ram.

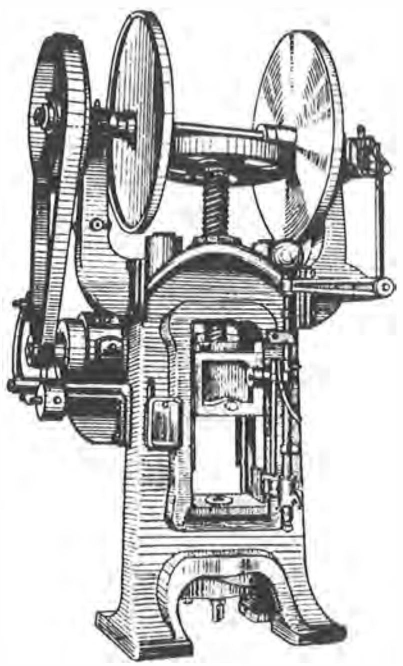

FIGURE 56. Friction press

The shortcomings of friction presses are their low productivity and poor accuracy. The height of this type of presses relative to their power is excessive.

Knuckle-joint presses are used for **embossing operations.** The main difference between these presses and ordinary crank presses is that in knuckle-joint presses the ram is connected to the crankshaft through an additional linkage (Figure 57), which generates considerable forces.

The force Q developed by the crank mechanism and applied to the point O of the linkage creates a force P directed perpendicular to Q, and in opposite directions. The force applied to the ram can be taken as $P = \frac{Q}{2} \tan \alpha$.

Because of design considerations the angle α at the end of the stroke must not exceed 87°30'. In this position we have $P_{max} = \frac{Q}{2} \tan 87°30' \approx 11.5Q$. In other words, the force obtained is almost 12 times as large as the force on the crankshaft. The gain in force is of course associated with a corresponding reduction in distance traveled. Knuckle-joint presses have therefore a relatively short stroke and also a relatively small number of strokes per minute (30 – 50).

Figure 58 gives a general view of the knuckle-joint press made by the East-German firm DIA.

Hydraulic presses serve the same purpose as knuckle-joint presses. They are used in watch production for embossing relief figures and symbols on dials, and for other similar operations.

Safety rules must be strictly observed when operating presses. The press design must include a two-hand starting lever, protection shields on the working parts of the press, devices preventing the introduction of hands into the danger zone during the motion of the ram, etc. The die sets must also be shielded, and the shield to be used must be indicated on the die-set drawings.

The smallest defect in the operation of the press or die set must be immediately reported, and work on the press stopped. Only the careful observance of all safety rules can prevent accidents.

The operator must be familiarized with these safety rules before he is put to work with presses and his knowledge of them should be refreshed periodically.

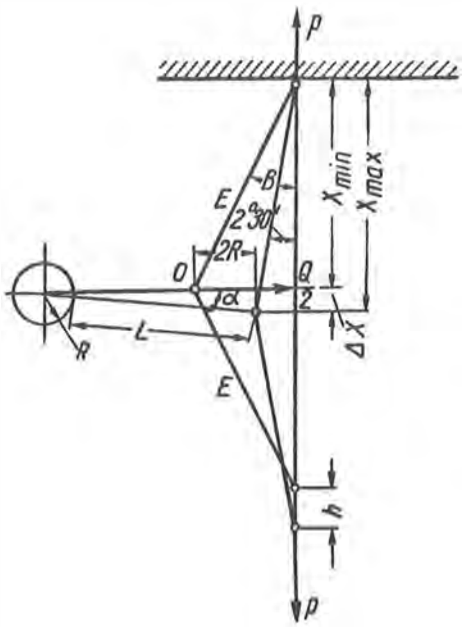

FIGURE 57. Diagram of the crank mechanism and the linkage of a knuckle-joint press

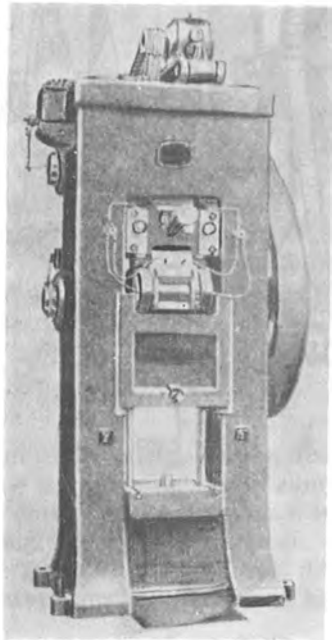

FIGURE 58. Knuckle-joint press DIA, made in Eastern Germany

Chapter IV

AUTOMATIC TURNING

Between 60 and 65% of the parts used in watches are machined on automatic lathes. Typical parts are shown in Figure 1.

The blanks for most of these parts must have accurate dimensions, a correct geometrical shape, and a high-quality finish.

The tolerance on the journal diameter of the balance staff, pallet staff, escapement pinion and fourth pinion of wristwatches does not exceed 0.005 mm, and a class 12 surface finish is required (class 13 in the case of the balance staff).

In order to achieve this accuracy and high-quality finish in the finished product, the blanks must have a class 8 or 9 surface finish (class 10 in particular cases) and a tolerance of 0.003-0.005 mm.

Subsequent polishing improves the surface quality to class 12 at the expense of a slight decrease in the dimensional accuracy. The blanks obtained from the automatic turning machines must, therefore, satisfy both the surface-quality requirements and tolerance. If the machined-part finish quality is only class 6 or 7, the part has to be ground.

Single-spindle automatic turning machines of the following two basic types are used in watch production: horizontal [Swiss-type] screw machines, and turret lathes*.

Swiss-type automatic screw machines are widely used in the manufacture of wrist- and pocket-watches and alarm clocks. Automatic turret lathes have a limited application in the manufacture of alarm clocks, and of table and wall clocks. Blanks are machined on the automatics from bar stock.

Operations such as generating cylindrical and shaped forms, taper turning, boring recesses, drilling and reaming holes, thread chasing and tapping, knurling outer surfaces, and milling screw head slots can all be performed on Swiss-type automatics.

The principle of operation of these machines is that the rotating bar stock is held by a headstock which advances the bar longitudinally through a guide bushing mounted in a fixed head (Figure 2). The stock is rigidly supported in the guide bushing, and protrudes from the headstock collet only enough to allow the bar to pass through the bushing and be turned directly in front of it.

The cutting tools are fastened in tool slides mounted on the same head as the guide bushing. The tools are displaced by means of cams and levers

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* For a description of the design and kinematic diagrams of automatic turret lathes, and for a calculation of their setups, cf. the book by B.A. Boguslavskii, Tokarnyie avtomaty i poluavtomaty (Automatic and Semiautomatic Lathes). — Mashgiz. 1948.

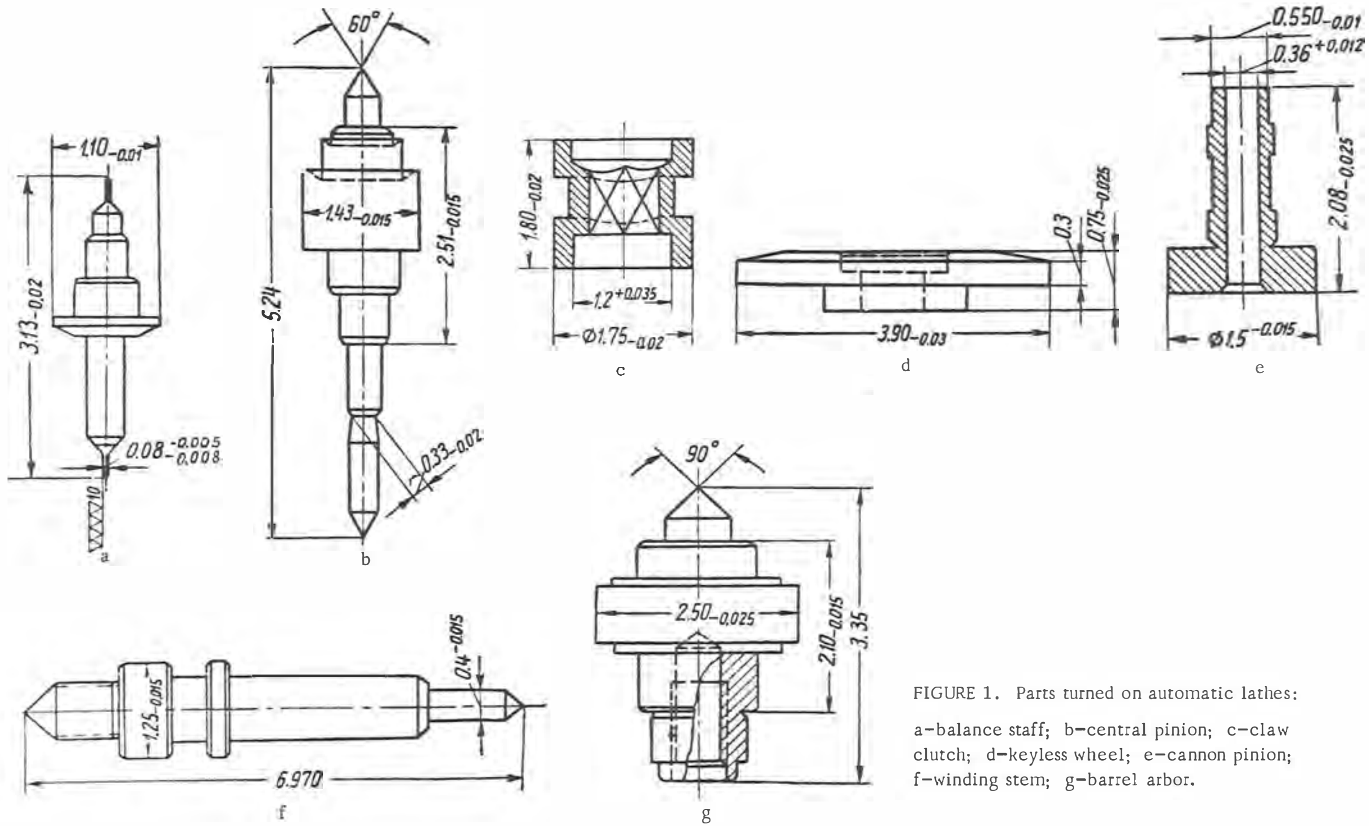


FIGURE 1. Parts turned on automatic lathes:

a–balance staff; b–central pinion; c–claw clutch; d–keyless wheel; e–cannon pinion; f–winding stem; g–barrel arbor.

in a radial direction in a plane perpendicular to the axis of the bar being machined.

When a cylindrical surface is being turned, the tool dwells with its point positioned at a distance from the bar axis equal to the radius to be machined. The headstock simultaneously advances at the proper feed rate.

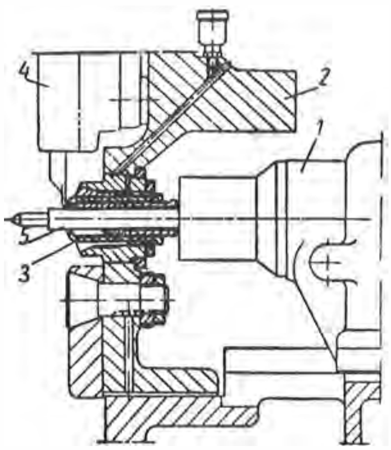


FIGURE 2. Basic scheme of operation of Swiss-type automatic screw machines:

1-headstock; 2-guide head; 3-guide bushing; 4-tool slide with cutting tool; 5-stock.

In taper turning, the tool moves in a transversal direction while the headstock advances.

By combining the motions of tool and headstock one can machine shaped surfaces of any given form.

Shaped surfaces can also be machined by form tools mounted in one of the tool slides.

Straight and stepped holes can be drilled and threads tapped using attachments mounted on a horizontal seat in front of the guide-bushing head.

Screw slots are milled by an attachment mounted on the machine bed on one side of the guide-bushing head.

After the cutting-off of a finished part, the collet is released, and the bar is pushed by a counterweight against the cutting tool which, at that moment, dwells in front of the guide-bushing hole. The headstock is retracted by a spring to a distance equal to the blank length, after which the collet regrips the bar.

The tool bits are positioned directly in front of the guide bushing, which supports the bar stock and absorbs the radial cutting forces, thus preventing the bending of the bar being machined.

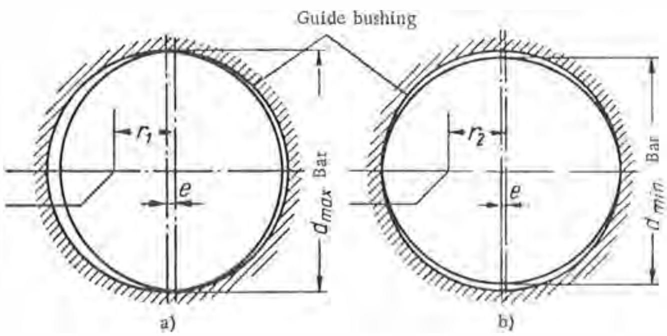


FIGURE 3. Diagram of the position of a slightly elliptical bar in the guide bushing

This arrangement makes it possible to machine to a high degree of accuracy low-rigidity parts (having a high length-to-diameter ratio), and stepped parts with any disposition of the steps.

One of the necessary conditions for turning high-accuracy blanks is the use of bar stock of uniform diameter.

Accordingly, bar stock supplied for Swiss-type automatics must satisfy rigid requirements, formulated in the special technical specifications (see Chapter Two).

When working with Swiss-type automatics, any ovality in the bar stock is reproduced on the machined surfaces.

Let us assume that the bar cross-section is elliptic (Figure 3), and that the difference between two mutually perpendicular diameters is 0.04 mm. Let the maximum diameter of the bar be 1.98 mm and the diameter of the bushing hole be 2 mm, and let the bushing hole be strictly circular. As seen in Figure 3, a, the bar will be pressed to the right side by the cutter, and the major axis of the bar ellipse will be displaced relative to the vertical diameter of the guide bushing by a distance e, in this case equal to $\sim$0.03 mm. The one-side clearance between bar and bushing will be $\sim$0.06 mm, and the turning radius is r_1.

When the bar is rotated by 90° (Figure 3, b), the distance e will be 0.01 mm, and the clearance between bar and bushing is 2.00-1.98 = 0.02.

The turning radius r_1 will be larger by 0.02 mm than r_2, and therefore the diameter turned will have roughly the same ellipticity as the bar, with the difference that the major axis of the turned ellipse will be displaced by 90° relative to the major axis of the bar ellipse.

In order to prevent jamming of the bar, the working surface of the bushing must be smooth and free of defects.

DESIGN OF THE MODEL 1A10P AUTOMATIC SCREW MACHINE

The following models of Swiss-type automatic screw machines are produced by the local industry: 1104P, 4 mm diameter maximum stock capacity; 1A10P, 7 mm diameter maximum stock capacity; and 1A12P, 12 mm diameter maximum stock capacity.

These models differ not only in size, but in design as well.

The 1A10P model (Figure 4) is widely used in watch production.

The machine comprises a base accommodating the drive, a bed with a camshaft, a headstock, a tool head with rocker arms, a device for feeding the bar, and a gear pump for the coolant.

Special attachments, mounted on the machine bed when necessary, permit centering and drilling, thread chasing and tapping and screw-head slot milling.

The kinematic scheme of the machine is shown in Figure 5. Rotation is transmitted from the electric motor pulley A (shaft I), by a flat belt, to pulley B on the main drive shaft II. The following are mounted on this drive shaft: the 120 mm diameter pulley (1), which transmits the rotation through a flat belt to the pulley on the headstock spindle III; the four-step pulley (C, D, E, F), which transmits the rotation through a V-belt to the jack shaft (countershaft) IV; the change pulleys (3), which transmit the rotation through a flat belt to the attachment spindles.

The change pulleys A and B provide for 17 spindle speeds (Table 1).

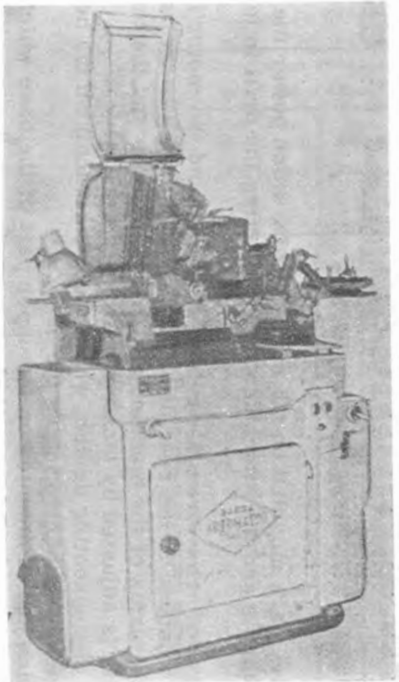


FIGURE 4. Model 1A10P Swiss-type automatic screw machine

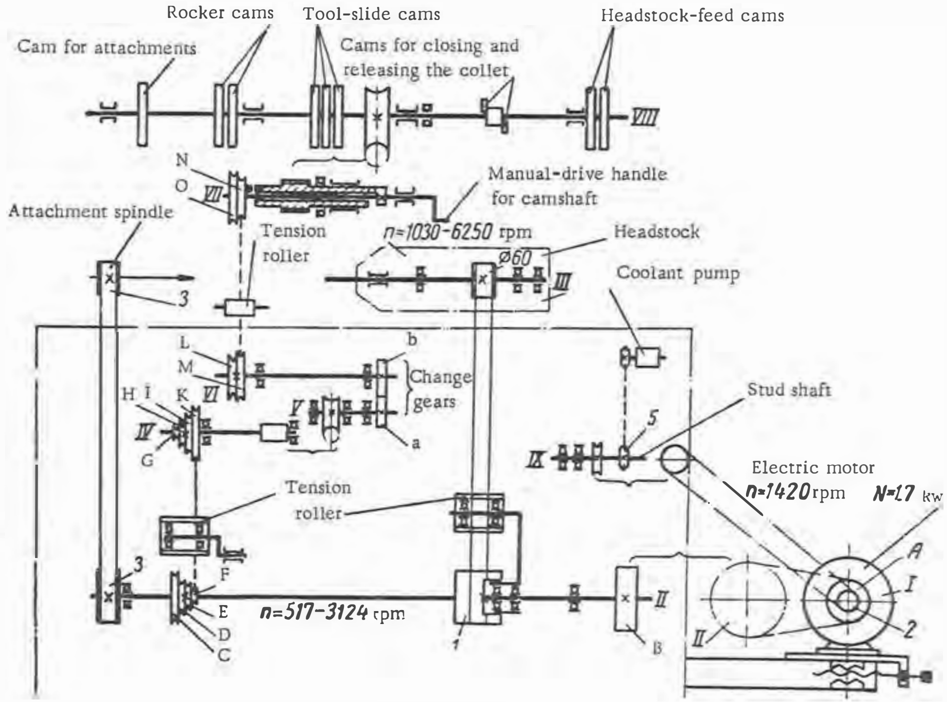


FIGURE 5. Kinematic scheme of the 1A10P automatic

TABLE 1

Spindle speeds

Spindle speed, rpm	Change pulleys A	Change pulleys B	Spindle speed, rpm	Change pulleys A	Change pulleys B	Spindle speed, rpm	Change pulleys A	Change pulleys B
6250	176	80	3180	176	157	1620	64	112
5550	176	90	2840	64	64	1450	64	125
5000	176	100	2520	64	72	1300	64	140
4460	176	112	2270	64	80	1160	64	157
4000	176	125	2020	64	90	1030	64	176
3570	176	140	1820	64	100			

The jack shaft IV drives the worm reduction gear (shaft V), from which the rotation is transmitted, through the change gears a and b and a two-step pulley fastened to shaft VI, to the transverse shaft VII, which in turn is connected by a worm and wheel with the camshaft VIII.

The stepped pulleys and the change gears make it possible to obtain 45 different camshaft speeds. Taking into account the 17 main drive-shaft speeds, we have 765 possible camshaft speeds (Table 2). Thus, the camshaft speed can be varied within wide limits, a fact which permits a rational utilization of the machine.

In addition to the pulley A, a second pulley (2) of 70 mm diameter is mounted on the electric-motor shaft; it powers the cooling-system pump through the shaft IX and a chain transmission.

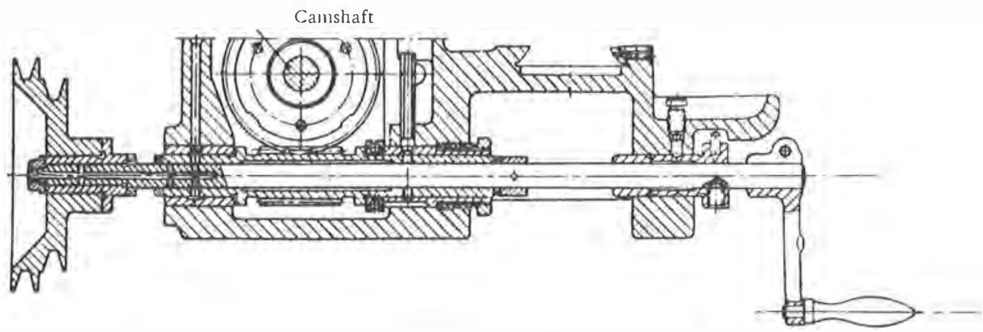


FIGURE 6. Camshaft drive

Fixed pulleys are mounted on the stud shaft IX which power the slotting attachment spindle and the attachment for retracting the drill in multiple drilling.

The base of the machine is of cast iron and the motor is mounted on a bracket attached to the rear of the base. The drives to the various working mechanisms of the machine are inside the base and the tension of the drive belts is adjusted by tension pulleys (idlers).

A special disconnecting device, which stops the machine if the headstock drive belt tears, is mounted inside the base.

The machine bed is mounted on the upper part of the base which is trough-shaped. The cutting fluid (coolant) pipes pass through the trough.

TABLE 2

Camshaft speeds (rpm) for the 1A10P lathe

Step No.	Designation of change gears and pulleys			Spindle speed, rpm																
	Pulleys	Gears		1030	1160	1300	1450	1620	1820	2020	2270	2520	2840	3180	3570	4000	4460	5000	5550	6250
		a	b	Camshaft speed, rpm																
1	FKLO	25	100	0.22	0.25	0.28	0.31	0.35	0.39	0.43	0.49	0.54	0.61	0.68	0.77	0.86	0.96	1.07	1.19	1.34
2	EILO	25	100	0.32	0.36	0.41	0.46	0.51	0.57	0.63	0.71	0.79	0.89	1.00	1.12	1.25	1.40	1.57	1.74	1.96
3	FKLO	35	90	0.35	0.39	0.43	0.49	0.54	0.61	0.68	0.76	0.85	0.95	1.06	1.19	1.34	1.49	1.67	1.86	2.09
4	FKMN	25	100	0.35	0.39	0.44	0.50	0.55	0.62	0.69	0.77	0.86	0.97	1.08	1.22	1.36	1.52	1.70	1.89	2.13
5	DHLO	25	100	0.45	0.50	0.56	0.63	0.70	0.78	0.87	0.98	1.09	1.22	1.37	1.54	1.72	1.92	2.15	2.39	2.69
6	EILO	35	90	0.50	0.56	0.63	0.71	0.79	0.89	0.99	1.11	1.23	1.38	1.55	1.74	1.95	2.17	2.43	2.71	3.04
7	EIMN	25	100	0.51	0.58	0.64	0.72	0.81	0.90	1.00	1.13	1.26	1.41	1.58	1.77	1.99	2.22	2.48	2.76	3.10
8	FKMN	35	90	0.55	0.61	0.69	0.77	0.86	0.96	1.07	1.21	1.34	1.51	1.69	1.89	2.12	2.37	2.65	2.95	3.31
9	CGLO	25	100	0.60	0.68	0.76	0.85	0.95	1.06	1.18	1.33	1.48	1.66	1.86	2.09	2.34	2.61	2.92	3.25	3.65
10	DHLO	35	90	0.69	0.78	0.87	0.97	1.09	1.22	1.36	1.52	1.69	1.90	2.13	2.39	2.68	2.99	3.35	3.72	4.19
11	DHMN	25	100	0.71	0.79	0.89	1.00	1.11	1.25	1.39	1.56	1.73	1.95	2.18	2.45	2.74	3.06	3.43	3.81	4.28
12	EILO	45	80	0.73	0.82	0.91	1.02	1.14	1.28	1.42	1.60	1.78	2.00	2.24	2.51	2.82	3.14	3.52	3.91	4.4
13	FKMN	45	80	0.79	0.89	1.00	1.12	1.25	1.40	1.55	1.74	1.94	2.18	2.44	2.74	3.07	3.43	3.84	4.26	4.79
14	EIMN	35	90	0.80	0.90	1.00	1.12	1.26	1.40	1.56	1.76	1.95	2.19	2.46	2.76	3.09	3.45	3.86	4.29	4.83
15	CGLO	35	90	0.94	1.05	1.18	1.32	1.48	1.65	1.84	2.07	2.30	2.58	2.89	3.25	3.64	4.06	4.54	5.05	5.68
16	CGMN	25	100	0.96	1.07	1.20	1.35	1.50	1.68	1.87	2.10	2.34	2.63	2.95	3.31	3.70	4.13	4.63	5.14	5.79
17	DHLO	45	80	1.00	1.12	1.26	1.41	1.58	1.76	1.96	2.20	2.45	2.75	3.09	3.46	3.88	4.33	4.85	5.39	6.06
18	DHMN	35	90	1.10	1.24	1.38	1.55	1.73	1.94	2.16	2.42	2.70	3.03	3.39	3.81	4.26	4.76	5.33	5.92	6.66
19	EIMN	45	80	1.16	1.30	1.45	1.63	1.82	2.03	2.26	2.54	2.83	3.18	3.56	3.99	4.47	4.99	5.59	6.21	6.99
20	CGLO	45	80	1.36	1.53	1.71	1.91	2.14	2.39	2.66	2.99	3.33	3.74	4.19	4.70	5.26	5.88	6.58	7.31	8.22
21	CGMN	35	90	1.49	1.67	1.87	2.10	2.34	2.62	2.91	3.27	3.64	4.59	5.14	5.76	6.43	7.20	8.00	9.00	10.01
22	FKLO	80	45	1.58	1.77	1.98	2.22	2.48	2.78	3.09	3.47	3.86	4.34	4.87	5.46	6.11	6.82	7.64	8.49	9.55
23	DHMN	45	80	1.60	1.79	2.00	2.24	2.51	2.81	3.12	3.51	3.90	4.38	4.91	5.51	6.17	6.89	7.71	8.57	9.64

TABLE 2 (cont'd)

Step No.	Designation of change gears and pulleys: Pulleys	Gears a	Gears b	Spindle speed, rpm: 1030	1160	1300	1450	1620	1820	2020	2270	2520	2840	3180	3570	4000	4460	5000	5550	6250
				Camshaft speed, rpm																
24	CGMN	45	80	2.16	2.42	2.71	3.03	3.39	3.79	4.22	4.74	5.27	5.92	6.64	7.45	8.34	9.31	10.42	11.59	13.03
25	FKLO	90	35	2.29	2.56	2.87	3.21	3.59	4.02	4.47	5.02	5.59	6.28	7.04	7.89	8.84	9.87	11.05	12.28	13.81
26	EILO	80	45	2.30	2.58	2.89	3.24	3.62	4.05	4.50	5.06	5.63	6.32	7.09	7.95	8.90	9.94	11.13	12.37	13.91
27	FKMN	80	45	2.51	2.81	3.15	3.52	3.94	4.41	4.90	5.51	6.13	6.88	7.72	8.65	9.69	10.82	12.11	13.46	15.14
28	DHLO	80	45	3.17	3.55	3.97	4.45	4.97	5.57	6.19	6.96	7.74	8.70	9.75	10.93	12.24	13.67	15.31	17.01	19.13
29	EILO	90	35	3.33	3.73	4.18	4.68	5.23	5.85	6.51	7.32	8.14	9.15	10.26	11.50	12.88	14.38	16.10	17.89	20.12
30	FKLO	100	25	3.55	3.98	4.46	5.00	5.59	6.25	6.95	7.81	8.69	9.76	10.95	12.27	13.75	15.39	17.19	19.10	21.48
31	FKMN	90	35	3.62	4.06	4.55	5.10	5.70	6.37	7.09	7.97	8.86	9.96	11.16	12.52	14.02	15.65	17.52	19.47	21.90
32	EIMN	80	45	3.65	4.09	4.58	5.13	5.74	6.42	7.14	8.02	8.92	10.03	11.24	12.60	14.12	15.76	17.65	19.61	22.06
33	CGLO	80	45	4.30	4.82	5.39	6.04	6.75	7.55	8.40	9.44	10.50	11.80	13.23	14.84	16.62	18.55	20.77	23.09	25.96
34	DHLO	90	35	4.58	5.13	5.75	6.44	7.20	8.05	8.96	10.06	11.20	12.58	14.10	15.81	17.71	19.77	22.14	24.61	27.67
35	DHMN	80	45	5.04	5.65	6.33	7.09	7.92	8.86	9.86	11.07	12.32	13.84	15.52	17.40	19.49	21.76	24.36	27.08	30.45
36	EILO	100	25	5.18	5.80	6.50	7.28	8.14	9.10	10.13	11.38	12.66	14.22	15.95	17.88	20.03	22.36	25.03	27.82	31.29
37	EIMN	90	35	5.28	5.92	6.63	7.43	8.30	9.28	10.33	11.60	12.91	14.50	16.26	18.23	20.42	22.80	25.53	28.37	31.91
38	FKMN	100	25	5.64	6.32	7.08	7.93	8.86	9.91	11.03	12.39	13.78	15.48	17.36	19.46	21.80	24.34	27.25	30.29	34.07
39	CGLO	90	35	6.22	6.97	7.80	8.74	9.77	10.93	12.16	13.66	15.20	17.07	19.14	21.46	24.04	26.84	30.05	33.40	37.56
40	CGMN	80	45	6.81	7.63	8.55	9.58	10.70	11.97	13.32	14.96	16.65	18.71	20.97	23.51	26.34	29.40	32.92	36.59	41.15
41	DHLO	100	25	7.12	7.98	8 94	10.02	11.19	12.52	13.93	15.65	17.41	19.56	21.93	24.59	27.55	30.76	34.43	38.27	43.04
42	DHMN	90	35	7.29	8.17	9.15	10.25	11.45	12.82	14.26	16.02	17.82	20.02	22.45	25.17	28.19	31.48	35.24	39.17	44.05
43	EIMN	100	25	8.21	9.20	10.31	11.55	12.90	14.44	16.06	18.05	20.08	22.56	25.29	28.35	31.76	35.46	39.70	44.12	49.62
44	CGLO	100	25	9.67	10.83	12.13	13.60	15.19	16.99	18.91	21.24	23.63	26.55	29.77	33.38	37.39	41.74	46.73	51.94	58.41
45	CGMN	90	35	9.85	11.04	12.37	13.85	15.48	17.32	19.27	21.65	24.08	27.06	30.33	34.01	38.10	42.53	47.62	52.92	59.53
Position of the change pulleys			*A*	64	64	64	64	64	64	64	64	64	64	176	176	176	176	176	176	176
			B	176	157	140	125	112	100	90	80	72	64	157	140	125	112	100	90	80

All the working mechanisms of the machine – the headstock on the right, the drilling and threading attachments on the left, and the tool head in the middle – are mounted on the b e d. The camshaft is mounted on the rear side of the bed and carries cams which control the headstock feed, the feeds of the upper tool slide, the rocker, the spindles of the drilling and other attachments, and the closing and releasing of the collet.

The camshaft is driven by the transverse shaft VII, mounted inside the bed (Figure 6). A two-step pulley turns freely on one end of this shaft while a handle is fixed to its other end by means of which the camshaft can be manually rotated when the machine is being adjusted.

The worm, with simple jaw clutches at both ends, turns freely on the transverse shaft.

The camshaft is rotated by the pulley when the worm clutch engages the latter, and manually when the worm engages the transverse shaft.

T h e h e a d s t o c k (Figure 7) consists of a cast-iron body, inside of which the hollow spindle (1) is mounted in two bearings. The frontal bearing is a bronze bushing (2), and the rear bearings are two radial-thrust bearings of the A accuracy class. The bar being machined passes inside the spindle and is clamped by the collet (3). The pulley (4), rotated from the main drive shaft, is fixed on the spindle between the bearings.

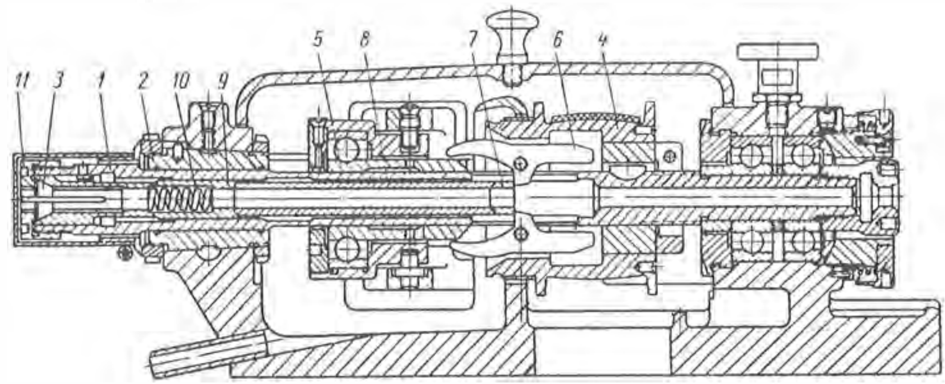


FIGURE 7. Headstock

The headstock moves longitudinally during the operation of the machine, and therefore the belt also moves along the wide pulley of the main drive shaft.

The collet mechanism is mounted on the spindle (1). If the slider (5) is moved to the right, the front ends of the cams (6) are forced apart. The cams, rotating on their axes, press the hardened bushing (7) forward. The bushing (7), by moving forward inside the spindle, applies pressure on the collet (3) through the tubes (8) and (9), thereby closing the collet. The collet is constantly pressed by the spring (10), against the nut (11), screwed onto the front end of the spindle.

If the slider (5) is moved to the left, the forward ends of the cams (6) are able to be drawn together by the spring (10), and the bushing (7) retreats, releasing the collet (3).

The motion of the slider (5) to the right and left is controlled by the fixed cams (3) and (4) on the camshaft through the fork lever (6) (Figure 8). As the headstock moves longitudinally during the machine's operation and the cams which open and close the collet are fastened in a fixed position on the camshaft, the lever (1) is provided with a channel slot in which slides the pin (2), held by the nut (7). The lever (1) turns about an axis mounted on the machine bed.

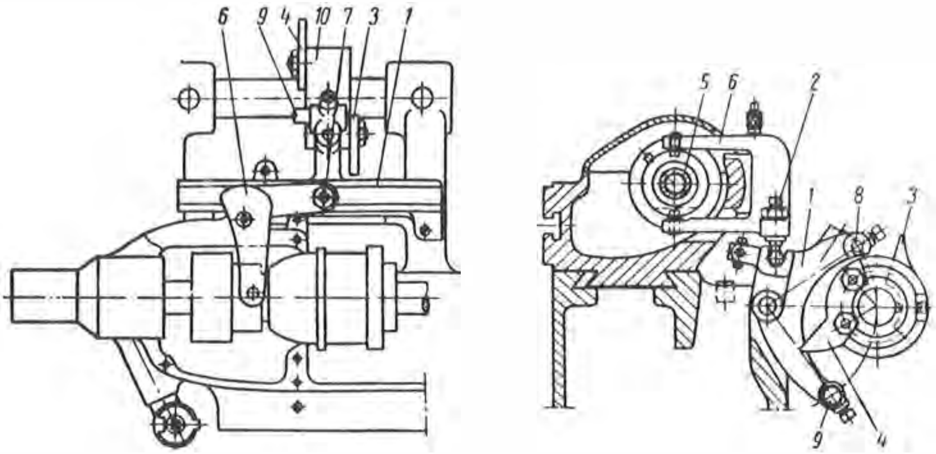


FIGURE 8. Design of the chucking system

The lever (1) carries the pins (8) and (9), which are engaged by the cams (3) and (4), fastened on the camshaft. The cam (3) releases, and the cam (4) closes the collet. The cams are so set on the faces of the disk (10) that they close and release the collet at definite points in the machining cycle.

The headstock is actuated through a feed mechanism by the plate cam B on the camshaft (Figure 9). The cam B, acting on the follower (1), rotates the lever C about its axis (2). The roller (3) on the lever C comes into contact with the roller (4) on the lever D. The lever C rotates in a vertical plane perpendicular to the spindle axis while the lever D rotates in a vertical plane parallel to the spindle axis. When the roller (3) is lifted, the lever D rotates to the left about axis (5) which is fastened to the machine bed.

The axis of the roller (6) is held in the slot of the lever D. The roller (6) engages on the cleat (8), mounted on the lateral face of the headstock body. When the lever D is rotated to the left the roller (6) feeds the headstock forward. The transmission ratio of the two arms of the lever D can be varied from 1:1 to 1:3 by means of the screw (7). The headstock is returned by means of a spring.

Two headstock-feed plate cams for machining two different parts can be mounted on the camshaft. Two followers (1) are mounted on the lever C and when the machine is changed over from one part to the other, the appropriate follower is lowered so that it does not engage its cam, while the other follower is lifted till it engages its cam.

T h e t o o l h e a d, sometimes called the tool post by analogy with the engine lathe, is a complex iron casting mounted on the machine bed (Figure 10).

The tool slides Nos 3, 4, 5, are mounted in a vertical plane on the front side of the head. An axis is fastened in the lower part of the tool head round which the rocker oscillates (Figure 11). The tool slides (1) and (2) are mounted at the extremities of the rocker. The horizontal slides with tools Nos 1 and 2, and the vertical slides with tools Nos 3, 4, 5 are advanced to the work through levers actuated by cams mounted on the camshaft and are returned by springs. Fine adjustment of the tools is provided for by equipping all tool slides with an adjusting device having micrometric screws and scales. When the rocker arm is rotated about its axis, tools Nos 1 and 2 move toward the bar axis along the arc of a circle of 42 mm radius; tools Nos 3, 4, 5 advance along straight lines.

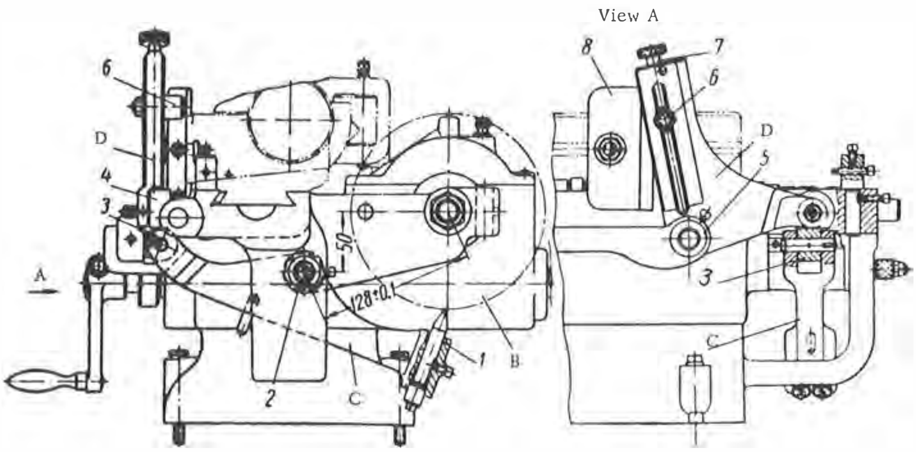


FIGURE 9. Headstock feed mechanism

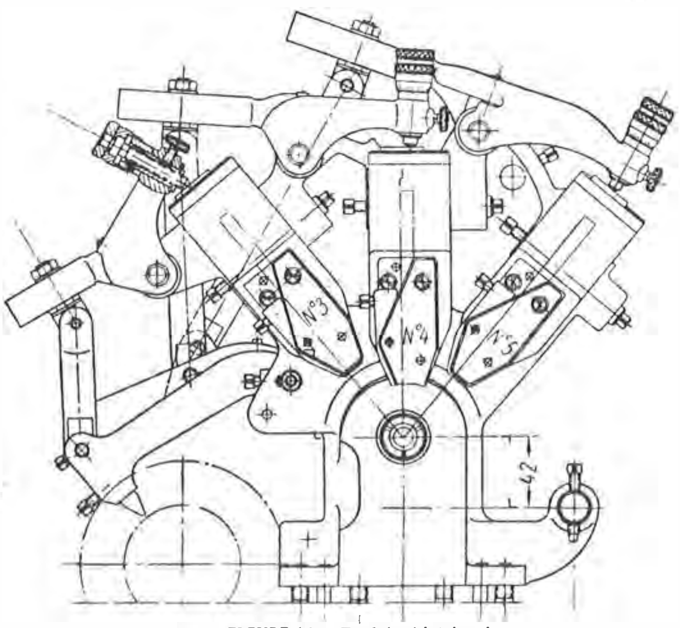


FIGURE 10. Tool (guide) head

The guide bushing, which supports the part of the bar protruding from the collet is mounted in the central part of the tool-head body. This support is unnecessary when short workpieces are machined. By removing the guide bushing and drawing the headstock nearer to the tool head the bar metal is used more economically, because the end scrap will be shorter.

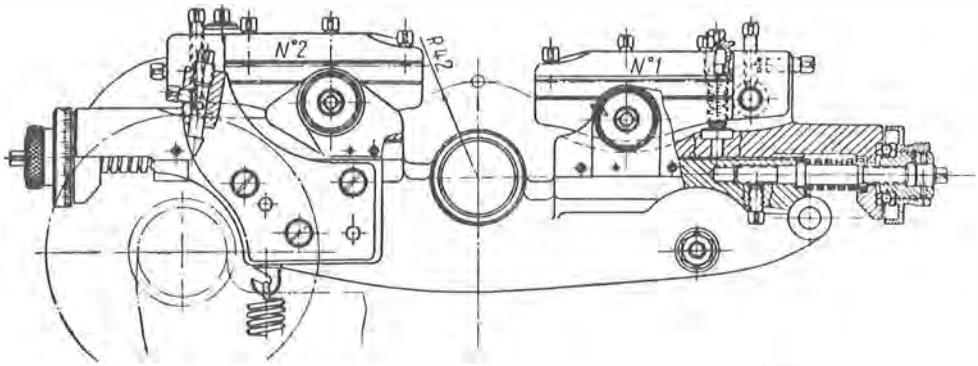


FIGURE 11. Rocker

Various types of guide bushing exist. An adjustable guide bushing is shown in Figure 12. The bushing (2), which carries the collet (3) with the carbide insert (4) is clamped in the collet (1). The opening diameter in collet (3) is adjusted by the nut (5), screwed on the end of the collet.

The bar feeder assembly consists of a tube mounted on two brackets, one of which is mounted on the back face of the bed, and the other on a special stand. The bar is pushed through the feed tube by action of a counterweight. When the collet is opened and the headstock retracts, the bar is pressed by gravity (on the counterweight) against the cutting tool, which is at that moment positioned directly in front of the guide bushing.

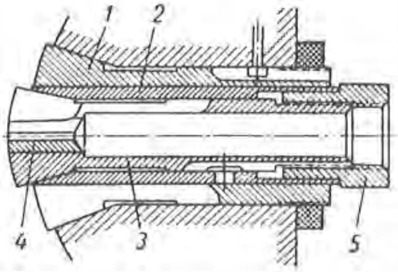


FIGURE 12. Adjustable guide bushing

The coolant supply system consists of a network of pipes through which the cooling liquid (cutting fluid) is supplied by a gear pump from the tank to the cutting tools.

The coolant is pure spindle oil or a mixture of 80 % spindle oil and 20 % paraffin oil. An emulsion is sometimes used. Splashing of the coolant is prevented by a jacket. The sliding surfaces of the machine are lubricated manually with an oiler. Worm-gear pairs and gear boxes are provided with oil baths.

Electrical equipment. The controls for the electric motor are placed on the control panel, located at the rear of the machine. Safety fuses guard against short circuits and a thermal relay protects against overloading of the motor.

The machine lighting network is powered by a 36 v source and the entire electrical system must be grounded.

Technical description of the 1A10P Swiss-type automatic lathe

Maximum bar diameter, mm	7
Maximum turning length, mm	50
Range of headstock-spindle speeds, rpm	1030—6250
Number of headstock-spindle speeds	17
Range of camshaft speeds, rpm	0.22—59.53
Number of camshaft speeds	765
Number of tool slides	5
Bar length, m	2
Shortest bar butt when working with a guide bushing, mm	78
Shortest bar butt when working without a guide bushing, mm	17
Power of motor, kw	1.7
Speed of motor, rpm	1420

These automatic screw machines are equipped with a set of removable attachments, which are, as a rule, mounted on the left part of the bed. The most important of those attachments are a single-spindle drilling attachment and a single-spindle threading attachment.

In addition, the following attachments can be supplied on request:

1. A two-spindle centering-drilling attachment.
2. A two-spindle combined drilling and threading attachment.
3. A three-spindle combined attachment for drilling and threading on two diameters.
4. A slotting attachment.
5. An attachment for reducing the travel of rocker tools.
6. An attachment for taper turning and for the automatic retraction of the drill at deep drilling.
7. An attachment for automatic stoppage in case of thread stripping.
8. A back-drilling attachment.
9. A recessing attachment.

A two-spindle attachment for centering and drilling deep holes of small diameter is shown in Figure 13.

The nonrotating centering spindle (1) is fed axially by the cam (4) through the lever (3).

The drilling spindle (2) is fed forward by a spring, and is withdrawn by the cam (5) through the lever (6). If repeated retractions of the spindle are necessary to remove chips and cool the drill, the push cam (8), which contacts the pin (7) of the lever (6), is installed. The cam (8) is rotated by the stud shaft IX of the machine drive through a worm-gear set and a pulley (see the kinematic scheme in Figure 5).

The successive shifting of spindles is performed by cam (9).

Various attachments are used for thread cutting. A combined two-spindle drilling – threading attachment is shown in Figure 14.

The drilling spindle of the attachment (not shown in the drawing) is actuated by the threading spindle through a gear pair (1) and can be locked so that it can move in the axial direction only.

The threading spindle (2) is rotated from the drive shaft of the machine through two flat belts. The belts are shifted from the idler (3) to the keyed pulley (4) or from the keyed pulley (4) to the idler (5) by a belt fork controlled by a cam mounted on the camshaft.

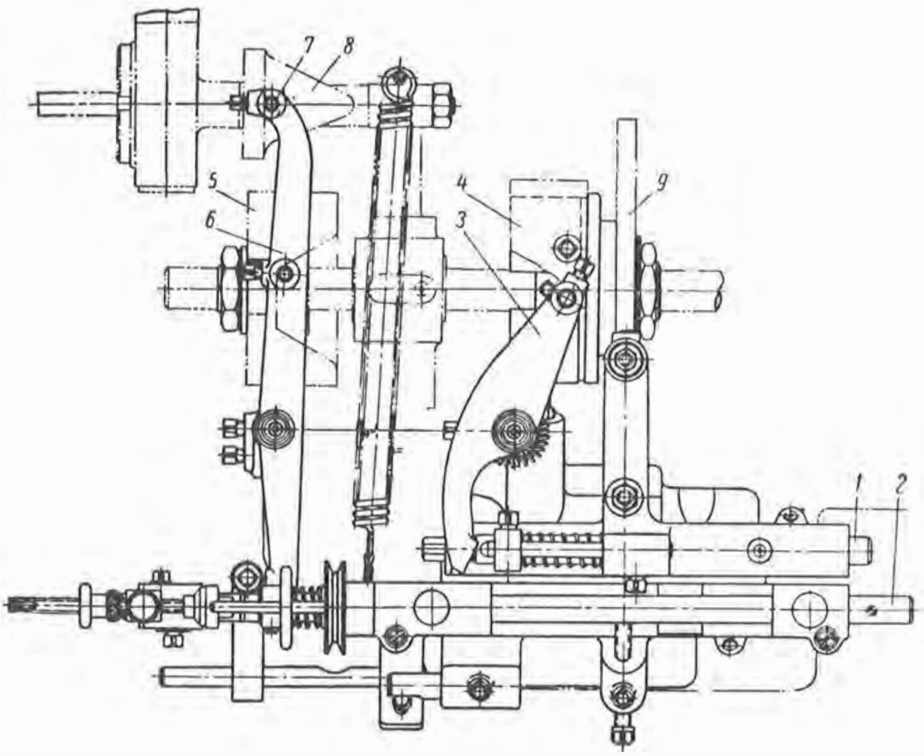


FIGURE 13. Two-spindle centering-drilling attachment

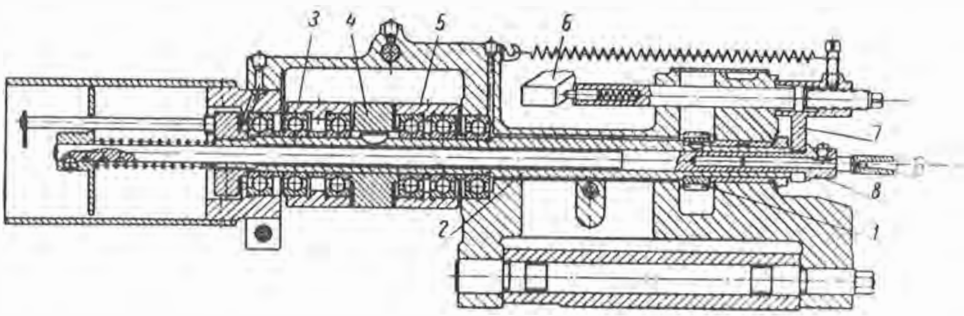


FIGURE 14. Two-spindle drilling — threading attachment

A cam mounted on the camshaft advances the threading tool into the work through the lever (6) which acts on the rod (8) through the tang (7).

The attachment has a device for shifting the spindles and adjusting them in the vertical, horizontal and longitudinal directions.

In addition to the above-described two-spindle attachment, a three-spindle combination attachment can be supplied if requested. One of the spindles serves for drilling and the other two for threading and tapping. The threading spindles can also be used for drilling. The attachment is suitable both for cutting two different threads on the same part and the use of two chasing dies and two taps of the same pitch.

In both attachments the spindle rotation must begin before the axial feed.

Automatic screw machines meet the following requirements for accuracy (according to specifications):

Radial run-out of the forward end of the headstock spindle	Not more than 0.003 mm
Radial run-out of the collet closer cone	Not more than 0.005 mm
Axial run-out of the spindle	Not more than 0.003 mm
Parallelism of the spindle axis and the direction of displacement of the headstock	0.005 mm on the length of displacement of the headstock
Radial run-out on a length of 35 mm of a mandrel chucked in the collet	Not more than 0.02 mm
Concentricity of the guide bushing and the machine spindle	0.005 mm
Radial run-out on the camshaft at the places where the headstock, rocker and slide cams are fitted	Not more than 0.010 mm
Parallelism of the bed guide planes and the spindle axis	0.005 mm

If the automatic screw machine satisfies the accuracy requirements, the stock diameter is accurate, and carbide tools are used, the total of diameter deviations, ovality and taper will not exceed 0.003 mm (for bar stock of diameter not larger than 3 mm). The axial dimensions of turned cylinders will not differ from one another by more than 0.008 mm.

PRODUCTION CAPABILITIES OF AUTOMATIC SCREW MACHINES

The capabilities of Swiss-type automatics are determined to a large extent by the tools which can be mounted in the tool-head slides and in the attachments available for these automatics. The following operations can be performed on the model-1A10P machine:

1. Turning and facing of cylindrical, conical and contoured outer surfaces.
2. Facing.
3. Recessing and chamfering.
4. Drilling and boring of holes.
5. Thread-cutting and tapping.
6. Slotting the heads of screws, bushings and other parts.
7. Broaching of square and other contoured holes.
8. Knurling outer surfaces.

The various uses to which cutting tools can be put on the 1A1OP machine are shown in Figure 15, while Figure 16 shows the shape of some tools.

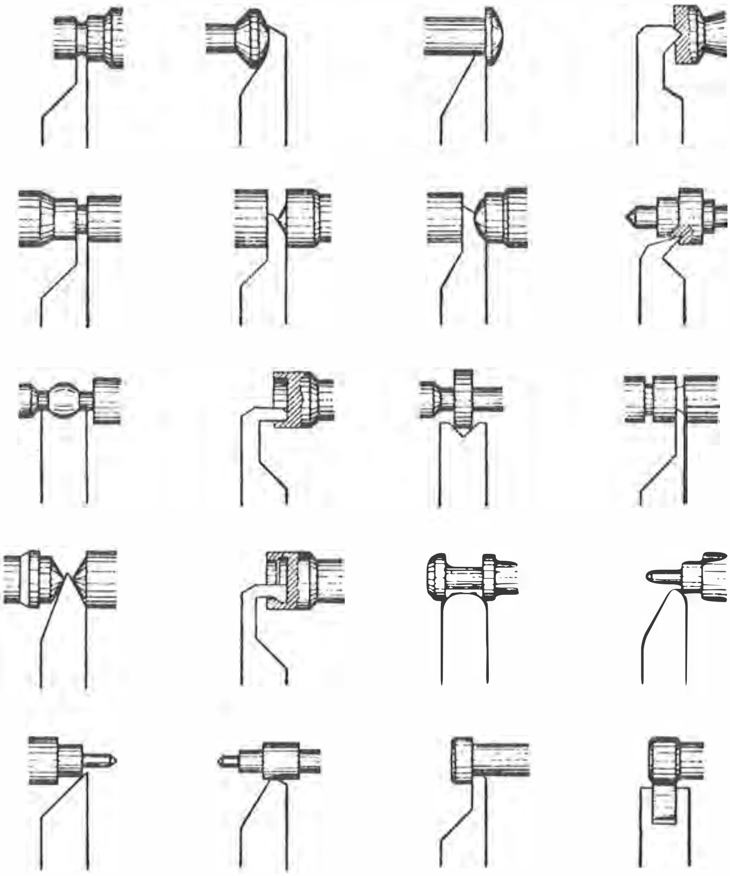


FIGURE 15. Diagram of the various uses of cutting tools

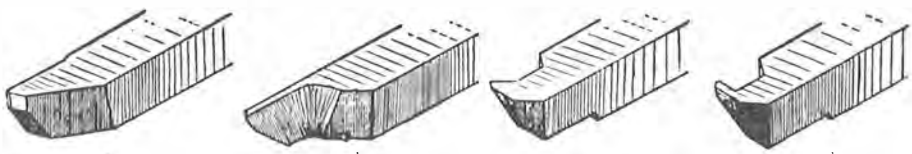


FIGURE 16. Tools of different shapes:

a–turning tool; b–cut-off tool; c–centering tool; d–boring tool.

Turning. Cylindrical surfaces are generally turned by rocker tool No. 1. The tool dwells, while the headstock advances at the predetermined longitudinal feed rate.

Small surfaces or recesses are machined by plunging tool No. 2 while the headstock is stationary.

The rocker is so designed that the feed motion of tool No. 2 and the withdrawal of tool No. 1 are produced by the rocker cam, while the withdrawal of tool No. 2 and the feed motion of tool No. 1 are induced by a spring. Tool No. 1 is not used in plunging operations, since the spring pressure could bend the part or break it. Instead of being cam-actuated, tool No. 1 can also operate on a fixed stop, a procedure used for machining the most accurate surfaces.

Tool No. 1 can turn several diameters in succession. When one diameter is finished, the tool retreats the necessary distance while the headstock dwells. When the tool is positioned for the second diameter, the headstock begins to advance.

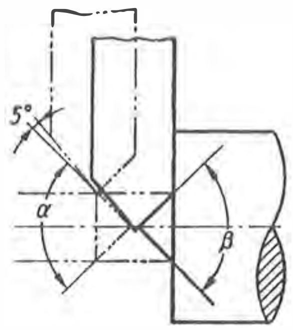


FIGURE 17. Scheme of cut-off with tool and headstock moving simultaneously

For taper turning, tool No. 1 and the headstock move simultaneously and uniformly. Contoured surfaces of any desired shape are obtained by feeding the tool and headstock simultaneously at suitable different speeds.

Rear-end taper turning is performed by the simultaneous feeding of the headstock and tool No. 4. Cone formation at cut-off is shown in Figure 17. The front-end cone in the following part is obtained by suitably grinding tool No. 4. In order to obtain a sharp apex in the front-end cone, the tool overruns the axis by 0.1 – 0.2 mm.

The sketch of the blank given on the operation sheet specifies a blank length which allows for the overrun.

The rear cutting edge of the cutter has a clearance angle of 3 to 5° in order to avoid rubbing the entire cutting edge along the cone surface. The cone surface obtained by simultaneously feeding the cutter and headstock is somewhat serrated as a result of tool traces.

Some watch parts have chamfers with dimensions ranging from 0.05 mm×45° to 0.15 mm×45°. Such chamfers are made either by the combined motion of cutter and headstock or by a suitably ground cutter cross fed. In the latter case slides No. 3 or No. 5 can be used.

It is sometimes more expedient to produce a chamfer by using the combined motion of cutter and headstock. Such a case is shown in Figure 31 (9th operation), where a 0.06 mm×45° chamfer is produced. In this case cutter No. 1 has a continuous backward motion during the formation of the shoulder and the chamfer; the headstock advances continuously from the beginning of the chamfering till the turning operation is completed. When a separate tool is used for chamfering, additional time must be expended on its approach and plunge, as can be seen from Figure 31 (16th operation). In addition, one of the tool slides is occupied by the chamfering tool.

The largest diameter of a part is sometimes not turned, since the bar stock can have the required diameter.

In cases where the part is subjected to heat treatment, however, or where the largest diameter is a mating surface, the bar must be turned on the largest diameter in order to remove surface scale or to attain a higher degree of concentricity, respectively.

Undercutting is usually performed by tool slides No. 4 or No. 5. The cutter is positioned for the operation by a cam. The headstock is then advanced to the undercutting depth, and is withdrawn when the undercutting is completed. The cutter then retreats to its initial position. The shape of the undercut is the same as the shape of the cutting tool. Undercutting can also be performed by means of tools mounted in the horizontal slides of an auxiliary attachment (Figure 18). Slides (1) and (2) are actuated through the levers (5) and (6) by the bell cams (3) and (4) on the camshaft. The slide carriage (8) is actuated by the flat cam (7).

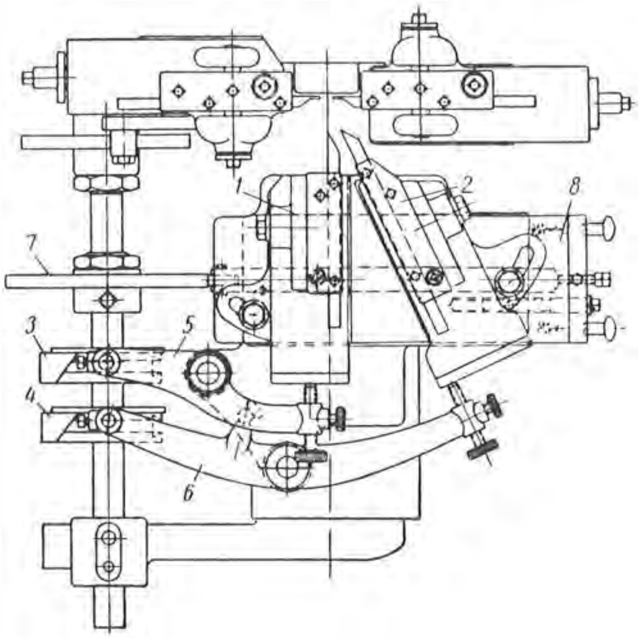


FIGURE 18. Attachment with two horizontal slides for undercutting

Back recessing, especially of deep recesses, should not be attempted on this type of automatic screw machine, as the cutting will take place at a considerable distance from the guide bushing, and the headstock, during the plunge, is withdrawn by a strong spring. This can lead to broken cutting tools. Parts having a back recess must therefore be started from the recess side. On the strength of these considerations the machining of the central pinion is started at the short end (see operation sheet on pp. 142-143).

Depending on the configuration of the part, the cutters can work in a different order as well. For instance, the cut-off may be performed by cutter No. 4 or 5, and the recessing by cutter No. 3. The distribution of work among the cutters is explained below.

D r i l l i n g. Holes are drilled by attachments mounted on the left part of the bed in front of the tool head. The drilled hole must be concentric with the outer surfaces, and accordingly the part must be accurately center-drilled (centered) before drilling.

The part is centered either by one of the vertical cutters, by a center drill mounted in a holder in a vertical slide (see Figure 19), or by a center drill mounted in one of the spindles of the attachment. Centering with a cutter is more accurate, although it involves a greater time expenditure.

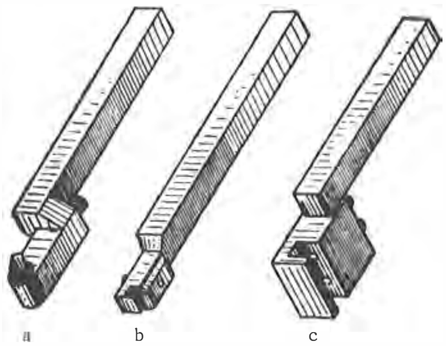


FIGURE 19. Holders:

a–for a center drill; b–for a carbide-tipped tool; c–for a common cutting tool.

Drilling without first centering is acceptable only if the hole depth does not exceed two diameters and if a strict concentricity between the hole and the outer surface is not required. The concentricity of the attachment and headstock spindles is very important when holes of a depth of more than two diameters are drilled.

In order to increase the productivity of the machine, centering or drilling must be combined with other operations as much as possible. Drilling, for instance, can be combined with turning. In drilling one must take into account that the total feed of the drill and the headstock must not exceed the admissible feed magnitude.

Centering and drilling will be accomplished with the highest degree of accuracy if the operation is started before the bar leaves the guide bushing.

A drilling operation should not begin with a considerable length of bar protruding from the guide bushing as the blank is then less stable and the machining might be inaccurate. It is not recommended to combine drilling and radial-feed machining.

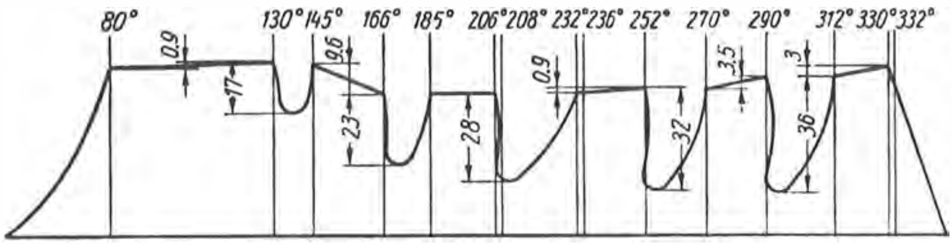


FIGURE 20. Layout of bell spindle feed cam for drill attachment, with recesses for retracting the drill

Stepped holes are drilled using two-, three-, and four-spindle attachments. The last spindle can be used for facing. Stepped holes are best drilled by separate drills, and not by step drills, in order to achieve accurate diameters and depth for each step. Straight-flute drills are generally used for drilling holes.

Blind holes and step holes with close depth tolerances are drilled using the headstock feed. Spindle feed is used when a through hole of uniform diameter is drilled.

In drilling deep holes, the drill is retracted many times in order to remove the chips and to cool the drill. The deeper the hole, the more frequent the retractions. The following relationships have been empirically established between the drill diameter, the hole depth, and the number of retractions of the drill:

Retraction	First	Second	Third	Fourth	Fifth
Drilling depth	3d	5d	6.5d	7.5d	8.5d

The bell cam which feeds the spindle of the drilling attachment has suitable recesses for retracting the spindle (Figure 20). It is, however, more expedient to retract the drill by means of a special cam mounted on the back wall of the bed (see Figure 13).

Thread chasing is carried out on automatic screw machines using the differential method, also called the overrunning method. The machine spindle rotates at the same speed and in the same sense as in turning while the spindle carrying the chasing die rotates in the same sense, but at a speed which is higher than that of the machine spindle when chasing a right-handed thread, and lower when chasing a left-handed thread. The speed of thread chasing is equal to the difference between the spindle speeds.

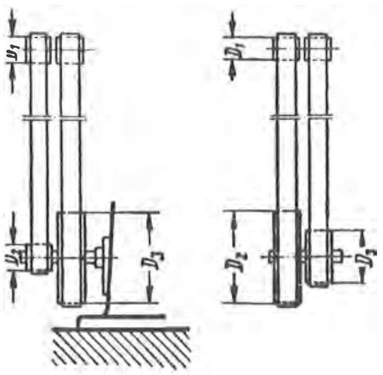


FIGURE 21. Thread-chasing attachment drive

When the chasing of a right-handed thread has been completed, the chaser begins to rotate more slowly then the machine spindle, and thus unscrews itself. The same effect is achieved in chasing a left-handed thread by reversing the sequence.

The differential method of thread chasing has many advantages over the method used in turret automatics, where the machine spindle is reversed and slowed down and the chasing die or tap is fixed in the turret head and has only a translatory motion. The switch-over of the machine spindle takes time and the design of the machine spindle assembly is much more complex.

Left-hand threads are chased using the same attachment as for right-handed threads with only the pulleys on the machine main drive shaft changing places (Figure 21).

For thread chasing, the headstock must first advance 5 to 8 mm at high speed, so that the cutters will not prevent the chaser from advancing along the whole length of the thread. After completion of the chasing, the headstock returns to its initial position. Thread tapping can be combined with cut-off, but only in the initial cut-off stage while the part is still rigidly connected to the stock.

The spindle speed necessary for chasing the thread is determined with the aid of Table 3, which gives the ratio between the chaser spindle speed and the machine spindle speed for the cutting speed adopted. The highest ratio is specified when chasing brass, and the lowest when tapping U10A steel. Intermediate values are selected in all other cases.

TABLE 3

Pulley diameters and the ratio of chasing die spindle (n_1) and the working-spindle (n) speeds when chasing a right-handed thread

Ratio of spindle speed $n_1 : n$	Pulley diameters*		
	D_1	D_2	D_3
1.12: 1	50	45	150
1.24: 1	50	45	165
1.35: 1	50	45	180
1.46: 1	50	45	195

* For the belt position see Figure 21.

The cutting speed is determined from the formula

$$v = \frac{\pi \cdot d_{ch}\ (n_1 - n)}{1000}. \qquad (1)$$

The working-spindle speed n_{ch}, necessary to chase a thread is determined from the formula

$$n_{ch} = z\frac{n}{n_1 - n}, \qquad (2)$$

where z = the number of thread turns.

Let us determine the value of n_{ch}, necessary for chasing a thread on the winding- key shaft (see operation sheet on pp. 138-139).

Assume n = 5550 rpm, and let the material be U7AV steel. We select from Table 3 the ratio $\frac{n_1}{n}$ = 1.12 and thus obtain n_1 = 5550×1.12 = 6216 rpm. The cutting speed will be $v = \frac{\pi \cdot 1.2(6216 - 5550)}{1000} \approx$ 2.5 m/min.

The number of revolutions necessary for chasing seven thread turns on the winding-key shaft will be (taking into account the approach of the chaser and the run-out)

$$n_{ch} = 7 \cdot \frac{5550}{6216 - 5550} = 58 \text{ revolutions}.$$

In addition the unscrewing of the chasing die requires

$$n_{uns} = 7 \cdot \frac{5550}{1875 - 5550} \approx 12 \text{ revolutions}^*.$$

---

* The absolute value is taken in the calculation.

In all 58 + 12 = 70 revolutions are required and this value is noted on the operation sheet. The unscrewing takes place at a chasing spindle speed of $n_1' =$ $= 1875$ rpm. ($n_1' = \frac{6216 \times 45}{150} = 1875$).

S l o t t i n g. Screw heads, bushings and rollers are slotted using a special attachment mounted horizontally on the bed (Figure 22).

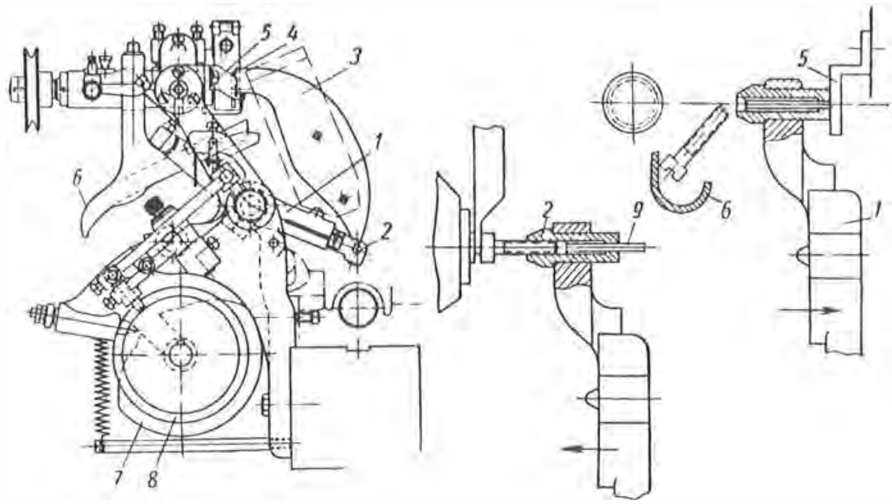


FIGURE 22. Slotting

1–lever; 2–pick-up bushing; 3–flap; 4–milling cutter; 5–knock-out cleat; 6–trough; 7–plate cam; 8–bell (edgewise) cam; 9–pin.

The slotting operation is carried out as follows. Just before cut-off the lever (1) takes up a position with the hole in the pick-up bushing directly opposite the part. The lever (1) is then moved along the bar axis by the bell cam, the bushing (2) is slid over the part and, when cut-off is completed, the lever, together with the part, takes up a new position opposite the slotting cutter (4). The flap (3) prevents the part from falling out of the bushing during its transport.

A cam advances the part into the slotting cutter.

The slotting-cutter spindle is powered from the stud shaft IX (Figure 5).

When the slotting has been completed, the lever (1) returns to its initial position, and the pin (9) in the pick-up bushing (2) contacts the cleat (5) and ejects the part into the trough (6). All motions of the lever (1) are controlled by the flat and bell cams (7) and (8), mounted on the camshaft.

When the slotting attachment is in operation, slides Nos 3 and 4 do not operate. Slide No. 3 is taken out of the tool head together with the bracket. The flap (3) is attached to slide No 4.

D i a m o n d k n u r l i n g is accomplished by knurling rollers in a holder mounted in slide No. 4 or No. 5 (Figure 23).

A longitudinal feed is used for knurling in order to prevent bending of the blank by radial stresses. The width of the knurling roller is, in this case, several times smaller than the length of the surface to be knurled.

B r o a c h i n g o f h o l e s o f s q u a r e a n d o t h e r s h a p e s is carried out using a broach chucked in the drilling-attachment chuck (Figure 24).

The broach rotates freely in the chuck and is fed toward the work by a spring, as in drilling. As the broach contacts the work, it is gripped by the rotating bar and rotates at the speed of the latter.

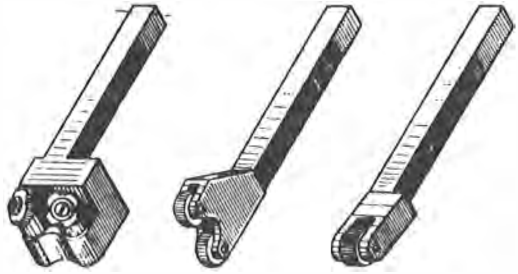


FIGURE 23. Knurling-tool configurations

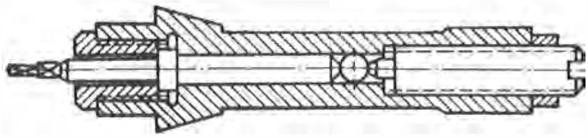


FIGURE 24. Chucking of a broach in the drilling-attachment spindle

The broach must be accurately centered relative to the previously drilled hole in the work. The chuck and spindle of the drilling device do not rotate during broaching.

Back drilling. This term refers to the drilling of a hole in the cut-off side of the part. To this end two attachments are mounted on the machine. One of the attachments is mounted in place of the milling attachment and the other is mounted behind the tool head and above the headstock. The first attachment feeds the part under the drill while the second rotates the drill. The spindle of the second attachment is driven from the stud shaftIX (see Figure 5). Figure 1, c is an example of a back-drilled part.

Tapers with angles of 3 to 5° are turned with the use of a special attachment mounted on the bed ways (Figure 25, a). The attachment increases the transmission ratio of the rocker levers from 3:1 to 10:1 (the rise transmitted from the cam to the rocker tools is reduced by a factor of up to 10). As a result, small inaccuracies in the cam profile do not in-influence the accuracy of the process. The most critical operations, with tolerances of 0.003 to 0.005 mm, are performed by the rocker tools with the aid of this attachment.

The attachment is usually used in combination with an undercutting attachment (Figure 25, b), the two attachments being mounted on a common base (1).

Two followers (3) are located at one end of the lever (2). One of the followers works with cam (4) intended for turning, and the other with cam (5), designed for plunging and undercutting. The lever rotates about axis (6).

The pin (7) is located at the opposite end of the lever and acts on the pin of the shoe (8), which is mounted directly in the rocker. Pins (7) and (8) drop when the profile of cams (4) and (5) rises, and as a result tool No. 1 retracts.

The undercutting attachment consists of a rigid plunger rod (9), mounted in the hinge mount (10). The mount is carried on the slide (11).

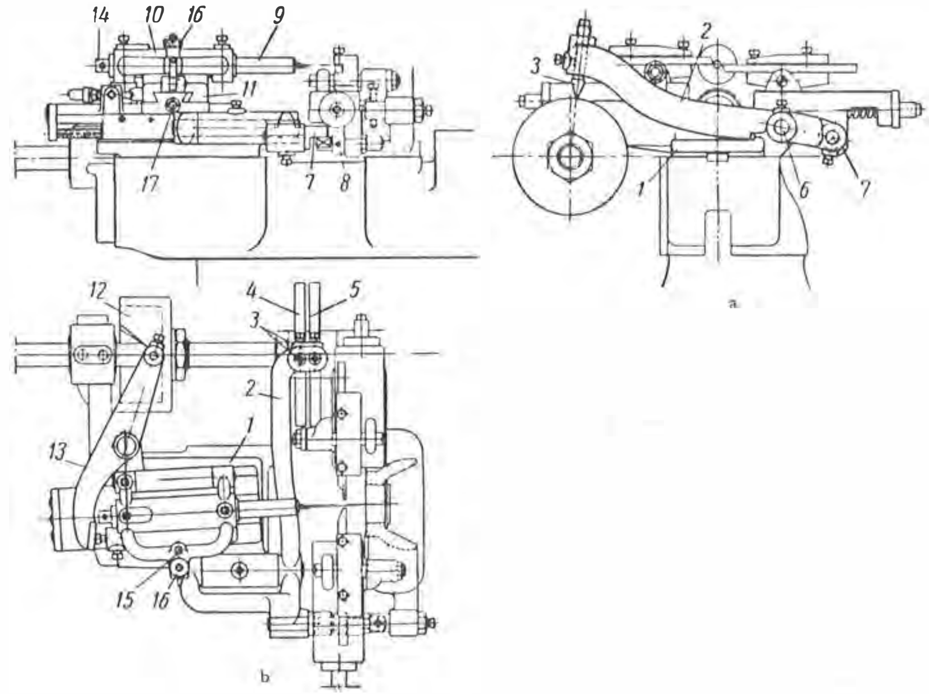


FIGURE 25. Attachment for reducing rocker travel and for recessing

The carriage is fed longitudinally by the cam (12) through the lever (13). The cutter is held in the collet of the rod (9) by the pin (14). The screws (15) and (16) serve for centering the rod in the vertical direction, and the screw (17) for setting the slide in the transverse direction.

The brief descriptions given above of operations performed illustrate the great versality of Swiss-type automatic screw machines which can be further broadened by the introduction of a fourth vertical slide and a third horizontal slide.

Only parts of extremely complex configuration, however, require this extra degree of versatility.

CUTTING CONDITIONS

The range of cutting speeds on the automatic screw machines is relatively narrow: from 20 to 60 m/min when machining steel, and from 30 to 100 m/min for machining brass.

The low cutting speeds are due to the small machining diameters and to the fact that when working at maximum spindle speed the machine vibration increases considerably, this being detrimental to the surface-finish quality.

It should be noted that the cross-sectional area of the chip is small when machining watch parts, and therefore the depth of cut is usually not taken into account when establishing the cutting conditions.

The cutting speeds and feeds recommended in Tables 4 and 5 are based on a systematization of the up-to-date experience of watch plants.

TABLE 4

Cutting speeds on Swiss-type automatic screw machines

Metal	Cutting speed, m/min
Steel U10A	20—40
Steel U7AV	20—60
Steel EI699	15—30
Brass LS63-3	30—100
German silver MNTsS63-17-18-2	30—60

TABLE 5

Feeds for U7AV steel worked on Swiss-type automatic screw machines, mm/revolution

Process	Surface-finish quality			
	7th	8th	9th	10th
Turning journals and chamfering pinions and shafts	—	0.010	0.008	0.005
Turning cylindrical, conical and contoured surfaces	0.015	0.010	0.008	—
Cut-off, plunging, facing and recessing	0.008	0.005	—	—
Turning nonworking surfaces	0.020	0.015	—	—
Drilling, centering	0.015	0.010	—	—

The cutting conditions recommended are not optimal and the cutting speeds and feeds can and should be increased as soon as improvements in the limiting elements make this feasible.

When using U10A or EI699 steels, the feeds recommended above must be multiplied by 0.9 and 0.8, respectively. When using type LS63-3 brass the feed should be multiplied by 1.2.

CALCULATION OF THE SETUP

Setup calculation involves planning the sequence of all operations and idle movements of the cutting tools and working parts of the automatic machine (allowing for possible overlappings), and the establishment of dwell intervals between operations. The setup must ensure that the finished part corresponds to the specified dimensions, tolerances and surface quality, and that its machining requires a minimum of time.

In order to draw the profiles of the cams which control all the motions of the working parts of the machine, it is necessary to determine the values of the headstock and tool motions, to select the cutting speed and feed, and to calculate the angles of rotation of the camshaft for the various operations and idle movements.

The cam curves are determined by two parameters: 1) the value of the central angle corresponding to the angle of rotation of the camshaft during the time of the operation or the idle movement; and 2) the value of the increment (or decrement) of cam radius (the value of the linear displacement of the given working part of the machine).

The cam curves are calculated so as to complete the entire cycle of operations and idle movements and to completely machine one part in one camshaft revolution. Sometimes 2 to 3 parts are completed during one revolution of the camshaft, as in the case of the part shown in Figure 26.

The machining of this part is simple. The bar already has the specified diameter and the only operations carried out on the machine are the chamfering of both ends and the cut-off. Three cycles are completed, and therefore three parts produced, for one camshaft revolution.

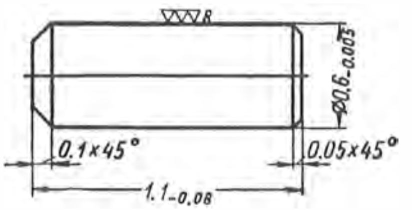


FIGURE 26. Wristwatch bridge pin

The cam rise for the operations and the idle movements depends on the ratio of lever arms selected. This ratio varies within certain limits for the headstock and for the rocker, while for the other mechanisms it is a constant magnitude (see Table 6).

Two headstock cams and three rocker cams can be mounted on the camshaft. Several cams are installed in order to speed up the process of changing over from machining one part to machining another. Aside from this, in complex setups the profile of the cam curve for some operations is split up into two or three profiles, thus creating the possibility of increasing the accuracy of the cams.

The travel of the headstock or the tool is defined as the difference between its initial and final positions. Thus, the value of the headstock travel will be equal to the length of the part plus the width of the cut-off tool.

The travel of cutters No. 2 (or 1), 3, 4, 5 is determined by the formula

$$s = C + \frac{D-d}{2} + a, \tag{3}$$

where C = distance from the initial cutter position to the bar;
D = bar diameter
d = machined diameter
a = tool cross-over.

The distance C (at cut-off) is usually 0.5 mm when machining bars of 3 mm diameter and up. When bars of smaller diameter are machined the cutters must be set at a distance of 2 mm from the bar axis in order to make sure of the free approach of the cutters in working position and the free passage of the bar between the cutters. The value of a is 0.1 to 0.2 mm.

Having determined the headstock or tool travel, the cam rise or drop is determined, taking into account the ratio of the lever arms. Thus, if the part length is 3.25 mm, the width of the cut-off tool 0.25 mm and the ratio of the headstock lever arms is 2:1, the stock-feed cam rise will be: $(3.25 + 0.25)2 = 7$ mm.

The maximum headstock lever ratio (3:1) is selected to minimize the influence of errors in the cam profile in those cases where a narrow tolerance must be held on axial dimensions. It must be kept in mind that according to the design data the maximum allowable cam rise is 50 mm.

The 2:1 lever ratio is recommended for the manufacture of long parts, since the rise curve corresponding to the 3:1 ratio is steep, especially for small radii, and jamming of the cam could occur.

TABLE 6

Lever arm ratios and cam dimensions for the 1A10P automatic screw machine

Displacement mechanism	Lever arm ratio	Basic cam dimensions, mm			
		maximum diameter	minimum diameter	hole diameter	cam thickness
Flat cams					
Headstock feed	from 1:1 to 3:1	160	60	20A	8
Rocker	3:1 and 10:1	120	70	20A	8
Tool slide No. 3 feed	1:1	120	70	28A	8
Tool slide No. 4 feed	2:1	120	70	28A	8
Tool slide No. 5 feed	2:1	120	70	28A	8
Bell cams					cam height
Centering-drilling attachment spindle feed	1:1	88	–	24	22
Drilling-threading attachment spindle feed	1:1	100	–	86	42
Slotting attachment lever feed	1:1	100	–	86	21

The motions of the working parts of the automatic machine can be classified as motions directly connected with the machining of the bar, and motions not directly connected with machining. Motions of the first type are called operations; motions of the second type – idle movements.

Calculation of the idle movements. When blanks of watch parts are machined on Swiss-type automatic screw machines, from 15 to 25% (35% in some cases) of the cycle time is taken up by idle movements which, obviously, should be kept at a minimum value in order to increase the productivity of the machine.

Some examples of idle movements are: releasing the collet, retracting the headstock, closing the collet, the approach and retreat of the tools, dwells, headstock advance when no external turning is necessary or when the bar is fed for chasing, etc.

It is usual to express idle movements by the number of degrees corresponding to a 1 mm rise or drop on the cam.

The number of degrees corresponding to 1 mm idle rise or drop for the same tool is a variable magnitude and depends on the production rate of the machine for the given part.

The higher the production rate, the more degrees are apportioned per mm idle movement.

When the production rate is low (up to 6 pieces per minute), the inertia forces on the moving parts of the machine are small and have no influence on the work, and can therefore be neglected. When the production rate is high (25 pieces per minute and more), the inertia forces become considerable, and if the idle movement curves are incorrectly calculated, the operation of the machine can be disturbed. Let us assume that the inertia forces in the lever driven by a cam follower (Figure 27) are quite considerable and exceed the tension of the lever spring. In that case the follower, on reaching the top point on the cam profile, will continue to rise because of inertia to some height h and in coming down will strike the cam. To avoid this, the rise curve must be made less steep or, in other words, the number of degrees per mm rise must be increased and the follower velocity at the end of the rise must be reduced to zero.

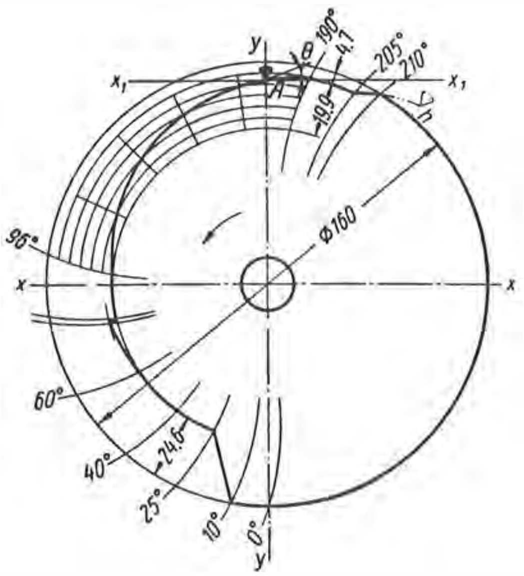


FIGURE 27. Headstock feed cam

The number of cam degrees apportioned to the idle movements is established on the basis of the machine production rate, taking into account the dynamic phenomena occurring at high camshaft speeds.

The optimal idle movements, in degrees, for the headstock and rocker cams, whose operation basically determines the production rate of the screw machine, are given in Tables 7 – 14.

It can be seen from the tables that the cam angle apportioned to idle movements increases with a decrease in cam radius. The reason for this is that a small rotation angle at small radii gives a very steep rise curve, which leads to rapid cam and follower wear and possibly, as was mentioned earlier, to jamming of the cam.

TABLE 7

Rocker cam

Cam angle for an idle movement, rise or drop; at a production rate below 6 pieces/minute

Cam radius at beginning of drop	Drop, mm											
	3	6	9	12	15	18	21	24	27	30		
Cam angle, degrees												
60	3	5	6	7	9	10	11	12	15	17	3	57
57	3	5	6	7	9	10	12	13	16	5	3	54
54	3	5	6	7	9	10	14	15	7	5	4	51
51	3	5	6	8	10	11	14	9	8	6	4	48
48	3	5	7	9	10	13	11	10	8	6	4	45
45	3	5	7	9	11	14	12	10	8	6	4	42
42	3	6	8	10	16	14	12	10	9	7	4	39
39	3	6	8	17	16	15	13	11	9	7	5	36
36	4	7	21	19	17	16	14	12	10	8	5	33
33	4	25	22	21	19	17	15	13	11	9	6	30
		30	27	24	21	18	15	12	9	6	3	Cam radius at beginning of rise
	Rise, mm											

TABLE 8

Rocker cam

Cam angle for an idle movement, rise or drop; at a production rate of 6 to 12 pieces/minute

Cam radius at beginning of drop	Drop, mm											
	3	6	9	12	15	18	21	24	27	30		
Cam angle, degrees												
60	4	6	8	10	12	14	16	19	21	23	5	57
57	4	6	8	10	13	14	17	19	21	6	5	54
54	5	6	8	11	13	15	17	20	10	6	5	51
51	5	6	9	11	13	16	19	10	10	6	5	48
48	5	7	9	12	14	17	15	10	10	7	5	45
45	5	7	10	12	15	18	15	11	11	8	5	42
42	6	8	10	13	21	19	16	13	11	8	6	39
39	6	8	11	24	22	19	16	14	11	8	6	36
36	6	9	27	25	22	20	17	15	11	8	7	33
33	6	30	28	26	23	20	18	16	13	10	7	30
		30	27	24	21	18	15	12	9	6	3	Cam radius at beginning of rise
	Rise, mm											

TABLE 9

Rocker cam

Cam angle for an idle movement, rise or drop; at a production rate of 12 to 25 pieces/minute

Cam radius at beginning of drop	Drop, mm: 3	6	9	12	15	18	21	24	27	30		
	Cam angle, degrees											
60	6	12	15	20	24	27	31	39	45	52	6	57
57	6	12	15	20	24	28	32	40	47	10	6	54
54	6	12	15	20	24	29	33	43	15	11	6	51
51	6	12	15	20	25	30	37	19	16	11	7	48
48	7	12	17	22	29	34	24	19	16	12	8	45
45	7	12	17	24	32	28	24	20	17	12	9	42
42	7	12	20	25	33	28	25	21	18	13	9	39
39	9	15	24	37	34	30	26	22	18	14	10	36
36	10	16	42	38	35	32	27	22	19	16	11	33
33	10	50	44	42	37	34	29	24	21	18	12	30
		30	27	24	21	18	15	12	9	6	3	Cam radius at beginning of rise
	Rise, mm											

TABLE 10

Rocker cam

Cam angle for an idle movement, rise or drop; at a production rate above 25 pieces/machine

Cam radius at beginning of drop	Drop, mm: 3	6	9	12	15	18	21	24	27	30		
	Cam angle, degrees											
60	10	13	17	23	27	32	37	45	50	57	10	57
57	10	14	18	23	29	33	40	46	53	13	10	54
54	10	15	19	24	29	35	41	47	17	14	10	51
51	10	15	20	25	30	37	43	23	18	15	10	48
48	10	16	20	26	31	40	27	23	19	15	10	45
45	10	16	21	28	35	32	29	24	20	16	10	42
42	10	17	23	29	37	33	29	26	20	16	10	39
39	11	18	25	45	40	35	30	26	21	17	11	36
36	12	19	50	46	41	37	31	28	23	18	12	33
33	13	57	53	47	43	40	35	29	25	19	13	30
		30	27	24	21	18	15	12	9	6	3	Cam radius at beginning of rise
	Rise, mm											

TABLE 11

Headstock cam

Cam angle for an idle movement, rise or drop; at a production rate below 6 pieces/minute

Cam radius at beginning of drop	Drop, mm: 5	10	15	20	25	30	35	40	45	50		
	Cam angle, degrees											
80	5	8	11	14	17	20	23	26	29	31	5	75
75	5	8	11	14	17	20	23	26	28	9	5	70
70	5	8	11	14	17	20	23	25	12	9	5	65
65	5	8	11	14	17	20	22	16	12	9	6	60
60	5	8	11	14	17	19	20	16	12	9	6	55
55	5	8	11	14	16	24	20	16	12	9	6	50
50	5	8	11	13	27	24	20	16	12	9	6	45
45	6	9	11	32	28	24	21	17	14	11	7	40
40	7	9	36	32	28	25	21	18	15	12	8	35
35	7	42	38	34	31	27	24	21	18	14	9	30
		50	45	40	35	30	25	20	15	10	5	Cam radius at beginning of rise
		Rise, mm										

TABLE 12

Headstock cam

Cam angle for an idle movement, rise or drop; at a production rate of 6 to 12 pieces/minute

Cam radius at beginning of drop	Drop, mm: 5	10	15	20	25	30	35	40	45	50		
	Cam angle, degrees											
80	7	12	16	21	26	31	36	41	46	52	7	75
75	7	12	16	21	26	31	36	41	47	12	7	70
70	7	12	16	21	26	31	36	42	17	12	7	65
65	7	12	17	22	27	32	38	23	18	13	8	60
60	8	13	18	23	28	34	28	23	18	13	8	55
55	8	13	18	23	29	34	29	24	19	14	9	50
50	9	14	19	25	39	34	29	24	19	14	9	45
45	9	14	20	45	40	35	30	25	20	15	10	40
40	10	16	51	46	41	36	31	26	21	16	11	35
35	11	58	53	48	43	38	33	28	23	18	14	30
		50	45	40	35	30	25	20	15	10	5	Cam radius at beginning of rise
		Rise, mm										

TABLE 13

Headstock cam

Cam angle for an idle movement, rise or drop; at a production rate of 12 to 25 pieces/minute

Cam radius at beginning of drop	Drop, mm											
	5	10	15	20	25	30	35	40	45	50		
	Cam angle, degrees											
80	11	19	28	37	45	53	61	68	76	82	8	75
75	11	20	28	37	45	53	60	68	74	15	9	70
70	11	20	28	36	44	51	59	65	22	16	9	65
65	12	20	28	36	43	50	57	29	23	17	10	60
60	12	20	28	35	43	49	36	30	23	17	10	55
55	12	20	28	34	41	43	37	30	23	17	10	50
50	12	20	27	34	51	45	38	31	25	18	12	45
45	13	20	27	59	53	46	39	33	26	20	14	40
40	13	20	67	61	54	47	41	34	28	22	16	35
35	15	75	69	62	55	49	42	36	30	24	18	30
		50	45	40	35	30	25	20	15	10	5	
		Rise, mm										Cam radius at beginning of rise

TABLE 14

Headstock cam

Cam angle for an idle movement, rise or drop; at a production rate above 25 pieces/minute

Cam radius at beginning of drop	Drop, mm											
	5	10	15	20	25	30	35	40	45	50		
	Cam angle, degrees											
80	13	23	34	44	56	64	75	86	96	105	12	75
75	13	24	34	44	55	64	75	85	95	20	12	70
70	14	24	34	44	55	64	75	85	28	20	13	65
65	14	24	34	45	55	64	74	37	29	21	13	60
60	15	25	35	45	54	63	46	38	30	21	14	55
55	15	26	36	45	54	55	46	39	31	22	15	50
50	16	28	37	45	64	55	48	40	32	24	16	45
45	18	28	37	74	65	60	49	41	33	25	18	40
40	19	28	83	74	67	60	50	42	34	27	20	35
35	20	93	84	77	68	61	52	44	37	30	24	30
		50	45	40	35	30	25	20	15	10	5	
		Rise, mm										Cam radius at beginning of rise

When working out the preliminary draft of the machine setup it is difficult to decide from which table to take the data on idle movements, the production rate for the given part being as yet unknown. In practice, therefore, a preliminary setup is calculated, taking the idle movements for the rocker and headstock cams from Table 15.

TABLE 15

Camshaft rotation angle for idle movements

Function of the cam	Section of the cam profile	Number of cam degrees per 1 mm rise or drop of the cam profile (idle movement)
Headstock displacement	Rise for headstock advance	1° per mm, but not less than 3°
	Drop for headstock retreat	0.5° per mm, but not less than 3°
Rocker control	Rise for advancing tool No. 2	1° per mm, but not less than 3°
	Drop for advancing tool No. 1	0.5° per mm, but not less than 3°
Shift of tool slides Nos. 3, 4, 5	Rise for advancing the tools	1° per mm, but not less than 3°
	Drop for withdrawing the tools	0.5° per mm, but not less than 3°
Drilling attachment control	Drill retraction for multiple drilling	0.75° per mm, but not less than 3° for the entire operation
Drilling and threading attachment spindle selection control	Rise and drop of the lever	20°
	Closing the collet	15°
Collet releasing and closing control	Releasing the collet	10°

After the preliminary calculation and the determination of the approximate production rate of the machine for the part in question, the definitive setup is calculated using the idle movements taken from the tables; and on the basis of this setup the actual production rate is determined. The data in Table 15 should be used in the final calculation only for the tool-slide cams [3, 4, 5], the collet cams and the attachment cams.

Safety dwells of 2 to 3° each are added when necessary to the values of the movements obtained in the setup calculation, in order to compensate for possible inaccuracies in the manufacture of the cam profile.

Laying out flat cams. The cam profiles must produce the uniform headstock or tool feed rate adopted with the selection of the cutting conditions. This condition is satisfied by the Archimedean spiral.

In order to plot the Archimedean spiral the angle of rotation of the cam corresponding to the given operation is split into several equal parts on the arc of a circle and rays are traced, connecting the center with the points of division.

The height of rise is split into an equal number of parts and concentric circles are drawn accordingly.

A continuous curve is drawn through the intersections of the rays with the corresponding circles and the resulting curve is an Archimedean spiral. Figure 27 shows an Archimedean spiral plotted on the sector from 96° to 190°. The rise is 19.9 mm.

In order that the interaction between cam and follower be correct, the angle θ between the tangent to the cam at the point of tangency and the perpendicular to the ray radius at the point of tangency, X_1X_1, must not exceed some specified value (Figure 27).

The angle θ is a variable magnitude in the Archimedean spiral, being larger at the beginning of the rise than at its end. It is recommended that this angle be less than 30°, since the pressure force could lead to jamming with higher angles. In addition, the follower prism wear increases with an increase in the angle θ.

If a roller follower is used instead of a prismatic follower, the angle can be increased by 5 to 8°, this being the difference between the friction angles in sliding and rolling friction, respectively.

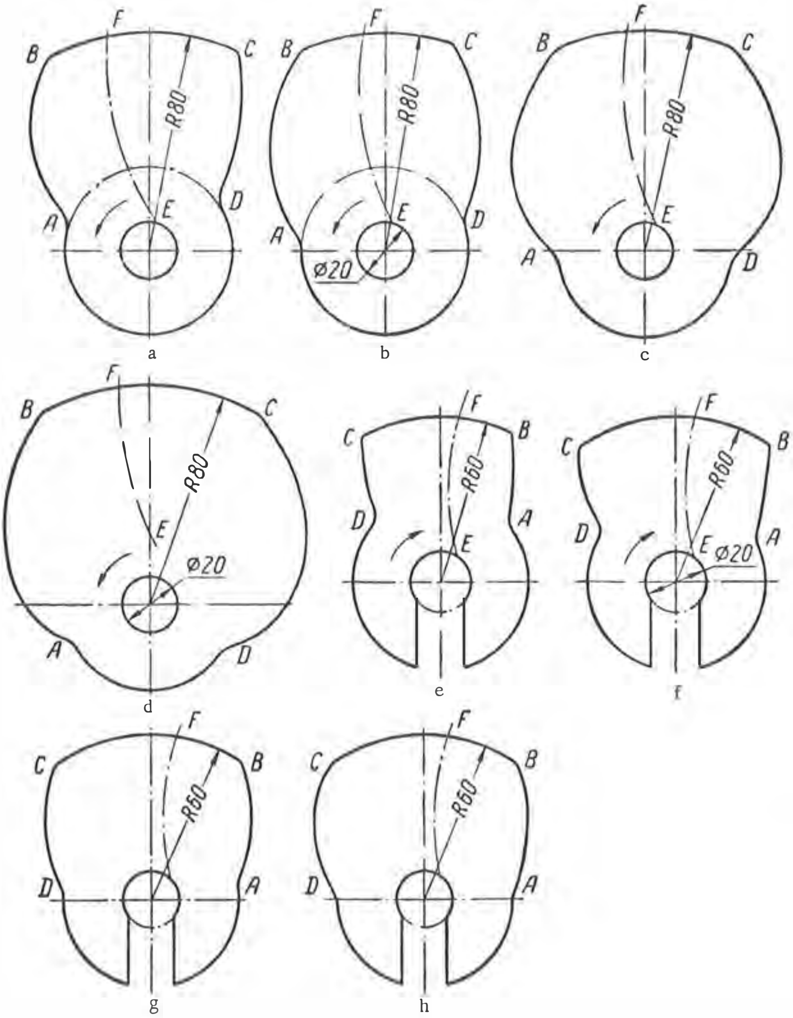


FIGURE 28. Templates for drawing idle movement cam profiles

1–headstock cam for a production rate of: a–up to 6 pieces/minute; b–6 to 12 pieces/minute; c–12 to 25 pieces/minutes; d–more than 25 pieces/minute; 2–rocker cams for a production rate of: e–up to 6 pieces/minute; f–6 to 12 pieces/minute; g–12 to 25 pieces/minute; h–more than 25 pieces/minute.

In order to reduce the angle or, in other words, to obtain less steep spirals, the most important cam profile sections should be located at large cam radii. It is best, from this point of view, to select the 1:1 lever arm ratio, as the curves will be less steep for this ratio.

The cam profile sections for idle movement, on the other hand, are so laid out that the follower speed will increase from zero, at the beginning, will reach a maximum in the middle of the movement, and will then drop to zero at the end of the movement.

When the production rate does not exceed 12 pieces per minute, the Archimedean spirals may serve as cam curves for the idle movements, though not really satisfying the above conditions. For small rises and drops the curves can be replaced by straight segments (Figure 27, sector 10 to 25°).

Cam layout is facilitated by the use of templates, which are usually included in the set of standard accessories for the machine.

Templates which correspond to Tables 7 – 14 are shown in Figure 28.

The assumption was made above that the follower moves along a straight line. Actually, it moves along a circular arc with a radius equal to the lever arm length, and the cam angles of rotation must therefore be referred to the intersection of the follower arc with the cam circle rather than to the intersection of the cam radius with its circle.

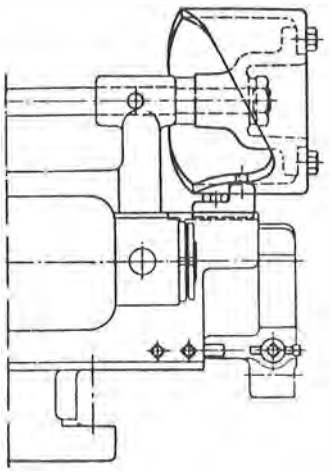


FIGURE 29. Bell cam

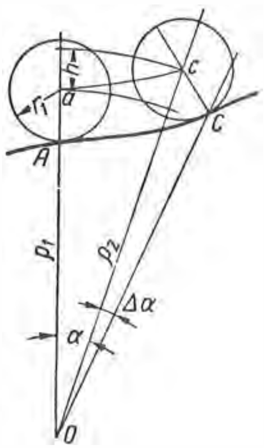


FIGURE 30. Cam profile AC, equidistant from the pitch curve ac

Bell cam profiles. In some models of automatic screw machines the headstock feed is controlled by bell cams (Figure 29). The calculation of the profiles of such cams is different from that for the above-described flat cams.

For a constant-velocity rise, the profile of the rim of the bell cam constitutes a helix. The idle-movement profiles, too, are helices with curvatures of 2 to 5 mm radius at both ends.

While most automatic screw machines use prismatic-toe, sliding-type followers, some present roller followers. The two types of followers differ not only in their friction coefficients, but also in the cam profiles they require for a given program. The cam profile for a roller follower depends on the value of the roller radius.

If we have a curve AC (Figure 30) along which a roller of radius r_1 rolls, the roller center will describe a curve ac, equidistant from the curve AC. It is usual to call this curve ac the p i t c h c u r v e.

The shape of the pitch curve differs from the shape of the cam profile in the places of transition from one curve to another. When calculating the cams, the angles of rotation α should be taken from the pitch curve, and not from the cam profile. The value h of the cam rise is equal to $\rho_2 - \rho_1$. The smaller the roller radius r_1 the nearer the shape of the pitch curve to that of the cam profile. In the case of a concave cam profile, the transitional curve must have a radius much larger than that of the roller.

The profiles of the drilling, threading, and slotting attachment bell cams are helices.

Order of the setup calculation. A sketch of the part is included in the operation sheet with dimensions, tolerances and finish-quality specifications. The type of material and bar gage, the tool-positioning scheme in two planes, and the cutting and spindle speeds for the maximum diameter to be turned, are also noted.

In dividing the work among the various tools and establishing the sequence of operations, it is well to remember that tool No. 1 is best for precise turning with longitudinal feed. Tool No. 2 is best for grooving; cutting-off should be done by tool No. 3 or No. 4; and contour turning, recessing and centering by tool No. 4 or No. 5.

Example of setup calculation for an automatic screw machine. We will present, as an example, the calculation of the layout of machining operations for the production of the winding key of the "Pobeda" brand wristwatch (see page 138).

In order to simplify the calculation, we will take the idle movements of the headstock and rocker from Tables 7 — 14 assuming that the production rate for the given part does not exceed 6 pieces/minute.

We introduce into the operation sheet a sketch of the part and specify the type of steel to be used. We specify 1.60 mm diameter bar stock, allowing 0.14 mm for removing the outer layer, since the 1.46 mm diameter is subsequently ground. Basing ourselves on the bar-stock diameter 1.60, we now introduce into the operation sheet sketches of the tool positions. The work is divided up among the various tools as follows*:

tool No. 1 turns the shoulder beyond the thread, one 0.06 mm × 45° chamfer and the 1.46 mm diameter for a length of 1.65 mm;

tool No. 2 turns the second 1.46 mm diameter section for a length of 1.45 mm, one 0.06 mm × 45° chamfer, the 1 mm diameter neck, the 0.08 mm chamfer and the 0.72 mm diameter journal;

tool No. 3 forms the internal chamfers 0.06 mm × 45°;

tool No. 4 cuts off the blank and turns the front and rear cones;

tool No. 5 turns the 0.88 mm wide groove.

We determine the initial distance from the tools to the bar as 1.2 mm. This dimension is necessary for the calculation of the idle movements. Taking into account that the given part has no complex configuration and that the process accuracy is relatively low, we fix the following lever arm ratios :

headstock	2:1
rocker	3:1
tool No. 3	1:1
tools Nos 4 and 5	2:1

We take the cutting speed for the maximum diameter to be 28 m/min, and therefore the spindle speed is 5550 rpm. In accordance with Table 3, we fix the ratio of the threading-attachment speed to the machine-spindle speed as 1.12:1.

----

* [For reference see drawing on page 140.]

We select the following sequence of operations:

1. The collet is released. The angle of rotation of the camshaft is fixed at 10° in accordance with Table 15. After the release of the collet the end of the bar is pressed by a counterweight against cut-off tool No. 4, which dwells in front of the guide bushing at that moment.

2. The headstock withdraws to its start position. Length of headstock travel is: $10.375 + 0.158 = 10.533$. The dimension 10.375 is the sum of the nominal dimension 10.450 and half the sum of the tolerances on the dimensions 3.40, 0.88, 4.52 and 1.65: $10.45 + \frac{(-0.10 + 0.02 - 0.03 - 0.04)}{2} = 10.375$ mm.

The dimensions 0.158 mm is the width of cut-off tool No. 4. In calculating length dimensions, half the tolerances are taken into account.

The angle of rotation of the camshaft for the drop $10.5 \times 2 = 21$ mm is set at 14°, in accordance with Table 11.

3. The collet closes. The angle of rotation of the camshaft is 15° according to Table 15.

4. Tool No. 4 withdraws to its original position. The travel is $2 + 0.10 = 2.10$ mm, where 0.10 mm is the tool cross-over. The angle of rotation of the camshaft is 3°, according to Table 15.

At the same time tool No. 1 approaches from its neutral position and is positioned for work (Figure 31). The travel of tool No. 1 is 1.45 mm, this being the difference (2 mm − 0.55 mm) where 2 mm is the distance from the bar axis to the neutral position of the tool, and 0.55 mm is the radius of the surface turned for the thread 1.2 mm (0.55 mm includes an allowance for the deformation of the metal by the threading).

5. The diameter for the thread is turned by tool No. 1. The headstock travel is

$$3.40 - 1.65 - 0.346 - 0.05 + 0.10 \text{ mm} = 1.454 \text{ mm},$$

where 3.40, 1.65, 0.346 are the dimensions from the sketch given in the operation sheet; 0.05 is half the tolerance on the dimension 3.40; and 0.10 is the initial distance from tool to bar.

We specify a feed of 0.03 mm. The number of spindle revolutions necessary to turning a part of this length will be $\frac{1.454}{0.03} = 48$.

6. Dwell for cleaning the face. The angle of rotation of the camshaft is 2°.

7. Tool No. 1 retracts for chamfering. The tool travel is $\frac{1.46 - 1.10}{2} - 0.06 = 0.12$ mm, where the dimension 1.46 is taken from the sketch; 1.1 mm is the diameter turned for the 1.2 mm thread; and 0.06 is the chamfer dimension.

The angle of rotation of the camshaft is 3°, from Table 15.

8. The chamfer is produced by the simultaneous motion of the headstock and tool No. 1. A 0.01 mm feed is chosen from Table 5 for chamfering at 45°. Both the headstock and the tool travel 0.06 mm, and the number of spindle revolutions necessary for performing the operation is therefore 0.06 : 0.01 = 6. This value is noted on the operation sheet.

As already mentioned above, the number of spindle revolutions necessary for performing all the operations is first calculated and then the number of cam degrees actually employed in working the part is computed (see below).

9. The 1.46 mm diameter is turned by tool No. 1 (Figure 31). The headstock travel is

$$1.65 - 0.06 - \frac{0.03}{2} = 1.575 \text{ mm},$$

where 1.65 mm = the length between shoulders according to the sketch;
0.06 mm = the width of the left chamfer;
$\frac{0.03}{2}$ = half the tolerance on the dimension 1.65.

The feed of 0.02 mm is taken from Table 5.

The number of revolutions is 1.575 : 0.02 = 78.

10. Dwell for cleaning the face surface. Angle of rotation of the camshaft is 2°.

11. Tool No. 1 withdraws to its neutral position. The travel is $2 - \frac{1.46}{2} = 1.27$ mm.

The number of degrees corresponding to this idle movement is 5, according to Table 7.

12. The headstock advances 6 mm rapidly for threading. The angle of rotation of the camshaft is 9°, according to Table 11.

13. An M 1.2 mm thread with a pitch of 0.25 mm is chased for a length of 1.40 mm. The number of spindle revolutions is calculated as follows:

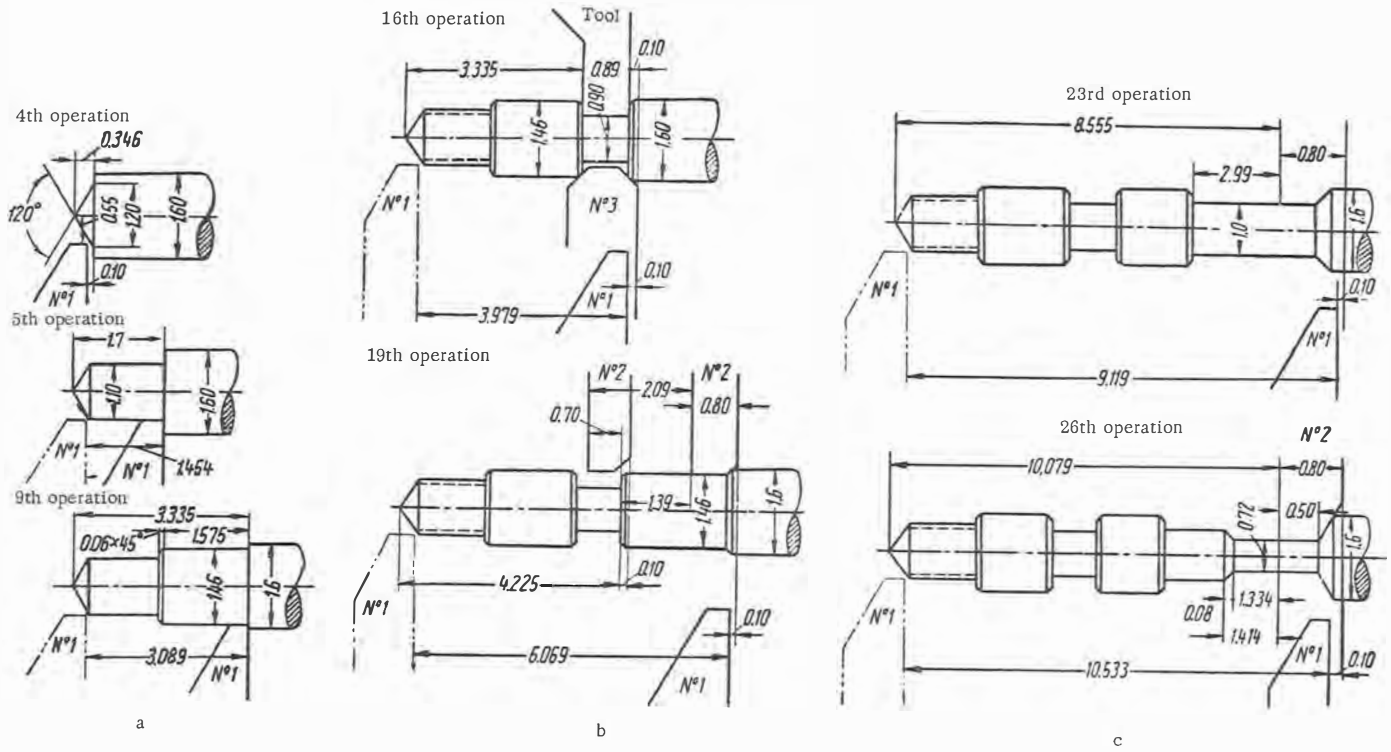


FIGURE 31. Various operations from operation sheet A-1

The spindle speed is 5550 rpm, and therefore the speed of the threading spindle will be $5550 \times 1.12 =$ $= 6216$ rpm, the coefficient 1.12 being taken from Table 3. The number of revolutions necessary for chasing seven threads, taking into account the safety clearance of one thread and the chaser approach (2 threads) will be $7 \times \frac{5550}{6216-5550} = 58$.

The number of revolutions necessary for unscrewing the chasing die will be $7 \times \frac{5550}{1875-5550} = -12$ (the unscrewing taking place at 1875 rpm). In all we need $58 + 12 = 70$ spindle revolutions for the operation.

14. The spindle recedes 5.11 mm, less than 6 mm by the width of tool No. 5. This is done in order to position tool No. 5 for work. The camshaft rotation is taken from Table 11 and is 6°.

15. Tools Nos 5 and 3 approach simultaneously. The travel is $2 - 0.8 - 0.03 = 1.17$ mm, where 2 and 0.8 are the tool neutral and work radii, respectively, and 0.03 is a safety clearance to prevent breakage. This idle movement requires 3°, according to Table 15.

16. Tool No. 5 plunges to a depth of 0.38 mm (Figure 31), where $0.38 = \frac{1.60-0.90}{2} + 0.03$ is the safety clearance from operation 15. The feed is taken from Table 5 and is 0.008 mm. The number of spindle revolutions will be

$$0.38 : 0.008 = 47.$$

Tool No. 3 simultaneously turns two chamfers, it being suitably ground to that end. The number of spindle revolutions necessary for this operation is 31, with a feed of 0.008 mm ($0.25 : 0.008 = 31$). The operation of tool No. 3 must be so arranged on the cam that its chamfering action is carried out after tool No. 5 has plunged to a depth of roughly 0.10 to 0.15 mm. The retraction of tool No.3 overlaps with the plunging of tool No. 5. Tool No. 3, positioned at an angle of 90° relative to tool No. 5, is more convenient for simultaneous chamfering than tool No. 4, which is positioned at an angle of 45° relative to tool No. 5.

17. Tool No. 5 dwells. Angle of camshaft rotation— 2°.

18. Tool No. 5 withdraws to its neutral position traveling 1.55 mm, a distance equal to its advances in operations 15 and 16. The camshaft rotation is 3° on the basis of Table 15. Tool No. 2 approaches as tool No. 5 withdraws. Its travel is $\frac{4-1.46}{2} = 1.27$ mm.

19. Tool No. 2 turns the external 1.46 mm diameter (Figure 31). The headstock travel is $1.45 - 0.06 +$ $+ 0.70 = 2.09$ mm, where 1.45 is the length dimension according to the sketch in the operation sheet; 0.06 is the length of the second chamfer; and 0.70 is the overlap of the edges of tools Nos 5 and 2. We fix; a feed of 0.02 according to Table 5. The number of revolutions necessary will be $2.09 : 0.02 = 104$.

20. A $0.06 \times 45°$ chamfer is turned by the simultaneous motion of the headstock and tool No. 2. The feed is 0.008 mm, as above. The number of spindle revolutions will be $0.06 : 0.008 = 7$.

21. Tool No. 2 plunges to the 1 mm diameter. The travel is $\frac{1.46}{2} - 0.06 - \frac{1.0}{2} = 0.17$ mm.

Table 5 indicates a feed of 0.01 mm. The number of spindle revolutions necessary will be $0.17 : 0.01 = 17$.

22. Tool No. 2 dwells. Angle of camshaft rotation— 2°.

23. Tool No. 2 turns the 1 mm diameter neck. The headstock travel is $4.52 - 1.45 - 0.08 = 2.99$ mm. The feed is 0.03 mm. The number of spindle revolutions necessary will be $2.99 : 0.03 = 100$.

24. A chamfer 0.08 mm long and 0.14 mm deep is turned by the simultaneous motion of the headstock and tool No. 2. The dimension 0.14 is half the difference between the diameter 1 and 0.72 mm.

The feed for tool No. 2 is 0.005 mm. The number of spindle revolutions necessary is $0.14 : 0.005 = 28$.

25. Dwell; the angle of rotation of the camshaft is 2°.

26. The 0.72 mm diameter journal is turned. The headstock travel is $1.65 - 0.36 - 0.02 + (0.864 - 0.8) =$ $= 1.334$ mm, where 0.36 mm is the length of the back cone;

0.02 mm is half the tolerance for the 1.65 mm dimension;

0.064 mm is the difference between the positions of the edge of tool No. 2 and the point of tool No 4.

A feed of 0.015 is chosen from Table 5. The number of spindle revolutions necessary will be $1.334 :$ $: 0.015 = 88$.

27. Tool No. 2 dwells; the camshaft rotation is 2°.

28. Tool No. 2 withdraws to its neutral position. Its travel is equal to the sum of its travels in operations 18, 20, 21 and 24: $1.27 + 0.060 + 0.17 + 0.140 = 1.64$ mm. The camshaft rotation is 3° (according to Table 7).

29. The headstock retracts $0.36 + 0.10 + 0.05 = 0.510$ mm where 0.36 mm is the cone length, 0.10 is the cross-over, 0.05 = the safety clearance of tool No. 4 to the journal.

The camshaft rotation is 5° (by Table 11).

30. Tool No. 4 advances from its neutral position and is positioned for work. Its travel is 2 — 0.36 — — 0.05 = 1.59 mm, where 0.36 is the journal radius and 0.05 is the safety clearance from the journal.

The camshaft rotation is 3° (by Table 15).

31. The back-end cone is turned by the simultaneous motion of the headstock and tool No. 4, while the part is simultaneously cut off from the stock, and the front cone of the next part is turned by the second edge of the tool. The travel of both headstock and tool No. 4 is 0.51 mm. The headstock feed is fixed by Table 5 at 0.015 mm. The number of revolutions necessary is 0.51 : 0.015 = 35.

The calculation is checked by summing all headstock movements, the advancing motions being taken as positive and the retracting motions as negative:

2.	— 10.533	20.	+ 0.060
5.	+ 1.454	23.	+ 2.99
8.	+ 0.060	24.	+ 0.08
9.	+ 1.675	26.	+ 1.334
12.	+ 6.000	29.	— 0.510
14.	— 5.110	31.	+ 0.510
19.	+ 2.09		

We obtain + 16.153 and — 16.153.

It is also necessary to check the tool displacements.

We now sum up the cam angles employed for actual machining and those required for idle movements. The idle movements take 94°, or 26% of the machining cycle. The cam angles for actual machining will accordingly be 360° — 94° = 266°.

The total number of spindle revolutions necessary for the actual machining of the part is 628 and the angle of camshaft rotation corresponding to one spindle rotation will accordingly be 266 : 628 = 0.425°. This number makes it possible to translate into camshaft degrees the spindle revolutions corresponding to each operation. The values obtained are introduced into the operation sheet and their sum must equal 266°.

The number of spindle revolutions, x, necessary for the machining of one part is obtained from the proportion

$$x : 628 = 360 : 266; \quad x = \frac{628 \times 360}{266} = 850 \text{ revolutions.}$$

The production rate of the machine is determined by dividing its usual spindle speed by the number of revolutions per piece :

$$A = 5550/850 = 6.6 \text{ pieces/minute.}$$

Since the calculated production rate exceeds the assumed rate of 6 pieces/minute only very slightly, there is no need to recalculate the layout.

Examples are given below of setup calculations for the machining of the central pinion and the cannon pinion.

The layout for the central pinion makes use of all five tools on the tool head and of one tool on a horizontal attachment. This last tool forms an undercut which serves for staking a gear on the $1.50^{-0.01}$ diameter.

The 0.15 mm undercut serves to ensure a well-defined seat of the gear against the face of the fitting shoulder on the pinion. This undercut is machined by tool No. 4.

The external diameter is not turned since gear teeth are later cut on it and it has an appropriate allowance.

After the end of the calculation the sums of all advancing and retracting headstock and tool motions are checked and should be equal to zero.

Laying out cams. Laying out the cams consists in transferring the calculated data from the operation sheet to a separate sheet of paper and plotting the cam profile. The maximum and minimum cam circles are traced and, for the rocker cam, an intermediate circle with R = 45 mm is also drawn. Beginning from the vertical axis and continuing in a clockwise direction, the values of the rotation angles given in the operation sheet are suitably marked.

Beginning from the outer or intermediate circle, the values of the displacements (taking into account the transmission ratio which also appears in the operation sheet) are marked on these lines.

As an example we will lay out the profile of the headstock cam for the production of the winding key shaft according to the operation sheet established by us. The angular increments are marked on the 160 mm diameter outer circle of the cam. An arc of 120 mm radius is drawn through the point 10° from the zero point (Figure 32). The radius of 120 mm corresponds to the length of the follower lever C (see Figure 9).

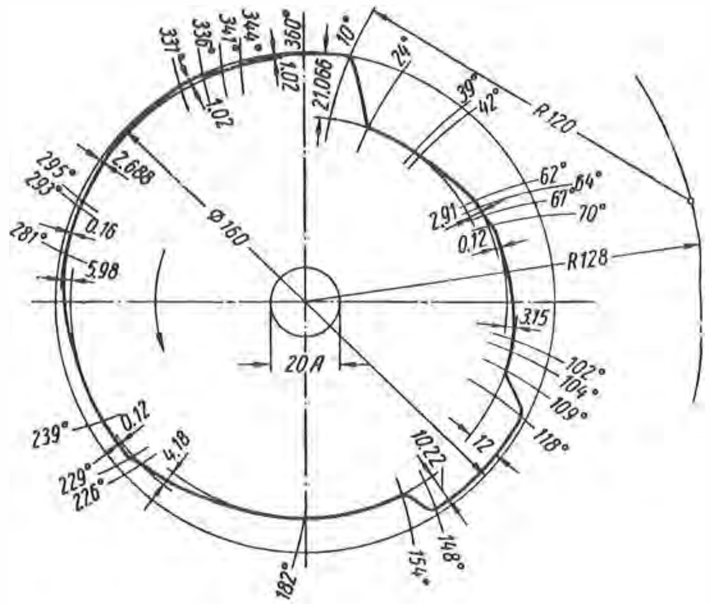


FIGURE 32. Headstock cam

In the sector in question the collet opens and the headstock dwells, and the cam profile is therefore an arc of a circle of 80 mm radius.

Corresponding to the retracting motion of the headstock, 14° are now marked and another 120 mm radius arc is drawn through the new division point. A circle of radius 80 — 21.066 = 58.934 mm is drawn (from the cam center) and its intersection with the arc drawn through the 24° point is found. According to the operation sheet, 21.066 mm is the drop on the cam. The points obtained are connected by a template curve.

A further 15° are laid off, corresponding to the closing of the collet. The headstock dwells, and therefore the profile is an arc of 58.934 mm radius.

When tool No. 4 recedes and tool No. 1 approaches, the headstock continues to dwell and therefore the 3° involved are marked along the same arc.

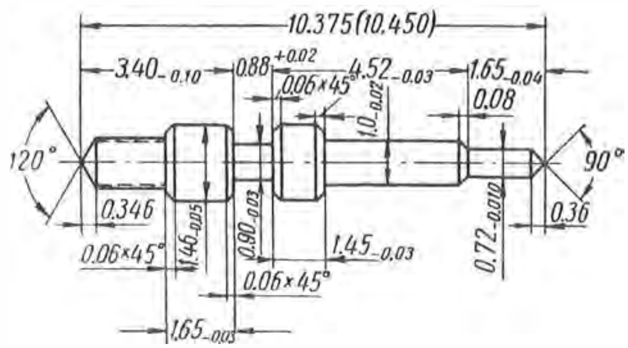
Between 42° and 62° a rise on the cam equal to 2.910 mm occurs. This rise is drawn according to an Archimedean spiral.

The cam profile is thus obtained, successively marking on the cam blank the values of the angles and the linear displacements listed in the operation sheet. The other cam profiles (for the tools, etc.) are drawn according to the same method.

Setup calculation
Sheet 4-1

Part No.	Part name	Material	Cutting speed
K-26-15	Winding key shaft	U7AV steel	28 m/min

Cam lever ratio	Headstock	Rocker	Tools Nos 3, 4, 5	Spindle rpm	5550
				Threading spindle rpm	6216
	2:1	3:1	1:1 2:1 2:1	Production rate 6.6 pieces per minute	



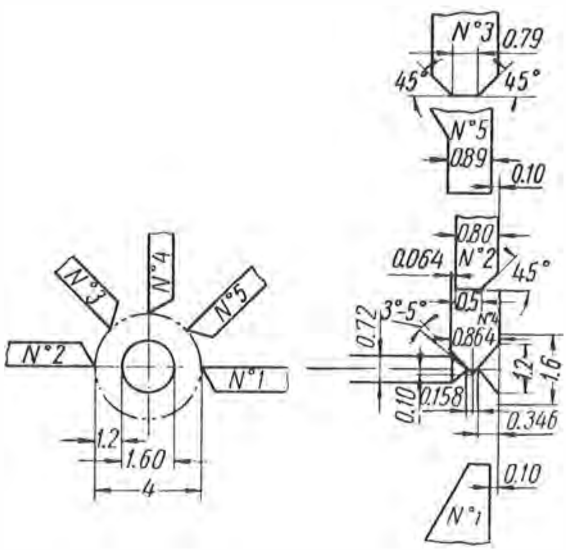
Setup calculation
Sheet A-1

Order of operations	Designation of operations	Headstock and tool travel	Cam lever ratio	Rise or drop on the cam	Feed per spindle revolution	Number of working revolutions	Cam rotation, degrees, for		Camshaft position, degrees	
							machining	idle movement	from	to
1st	Release collet .	—	—	—	—	—	—	10	0	10
2nd	Retract headstock	10,375 + + 0.158 = = 10.533	2	21.066	—	—	—	14	10	24
3rd	Close collet . .	—	—	—	—	—	—	15	24	39
4th	Retract No. 4 .	2 + 0.1 = 21	2	4.2	—	—	—	3	39	42
	Approach No. 1	1.45	3	4.35	—	—	—	(3)	39	42
5th	Advance headstock	1.454	2	2.91	0.03	48	20	—	42	62
6th	Dwell	—	—	—	—	—	—	2	62	64
7th	Retract No.1 . .	0.120	3	0.360	—	—	—	3	64	67
8th	Advance headstock	0.06	2	0.12	0.010	6	3	—	67	70
	Retract No. 1 .	0.06	3	0.18	0.010	(6)	(3)	—	67	70
9th	Advance headstock	1.575	2	3.15	0.02	78	32	—	70	102
10th	Dwell	—	—	—	—	—	—	2	102	104
11th	Retract No. 1 .	1.270	3	3.810	—	—	—	5	104	109
12th	Advance headstock	6	2	12	—	—	—	9	109	118
13th	Thread	1.40	1	1.40	(0.25)	70	30	—	118	148
14th	Retract headstock	5.11	2 2	10.22	—	—	—	6	148	154
15th	Approach No. 5	1.17	2	2.34	—	—	—	3	154	157
	Approach No. 3	1.17	1	1.17	—	—	—	3	154	157
16th	Plunge No. 5 .	0.38	2	0.76	0.008	47	20	—	157	177
	Plunge No. 3 .	0.25	1	0.25	0.008	31	(14)	—	158	172
	Retract No. 3 . to neutral . .	1.42	1	1.42	—	—	—	(3)	172	175
17th	Dwell	—	—	—	—	—	—	2	177	179

Sheet A-1 (cont'd)

Part No.	Part name	Material	Cutting speed
K-26-15	Winding key shaft	U7AV steel	28 m/min

Cam lever ratio	Headstock	Rocker	Tools Nos 3, 4, 5	Spindle rpm	5550
				Threading spindle rpm	6216
	2:1	3:1	1:1 2:1 2:1	Production rate 6.6 pieces per minute	



Sheet A-1 (cont'd)

Order of operations	Designation of operations	Headstock and tool travel	Cam lever ratio	Rise or drop on the cam	Feed per spindle revolution	Number of working revolutions	Cam rotation, degrees, for		Camshaft position, degrees	
							machining	idle movement	from	to
18th	Retract No. 5 to neutral . .	1.55	2	3.10	—	—	—	3	179	182
	Approach No. 2	1.270	3	3.810	—	—	—	(3)	179	182
19th	Advance headstock	2.09	2	4.18	0.02	104	44	—	182	226
20th	Advance headstock	0.060	2	0.12	0.008	7	3	—	226	229
	Advance No. 2	0.060	3	0.180	0.008	(7)	(3)	—	226	229
21st	Advance No. 2	0.170	3	0.510	0.010	17	8	—	229	237
22nd	Dwell	—	—	—	—	—	—	2	237	239
23rd	Advance headstock	2.99	2	5.98	0.03	100	42	—	239	281
24th	Advance headstock	0.08	2	0.16	—	(28)	(12)	—	281	293
	Advance No. 2	0.140	3	0.420	0.005	28	12	—	281	293
25th	Dwell	—	—	—	—	—	—	2	293	295
26th	Advance headstock	1.334	—	2.668	0.015	88	36	—	295	331
27th	Dwell	—	—	—	—	—	—	2	331	333
28th	Retract No. 2 .	1.640	3	4.920	—	—	—	3	333	336
29th	Retract headstock	0.510	2	1.020	—	—	—	5	336	341
30th	Approach No. 4	1.590	2	3.180	—	—	—	3	341	344
31st	Advance headstock	0.510	2	1.020	0.015	35	16	—	344	360
	Advance No. 4	0.510	2	1.020	0.015	(35)	16	—	344	360
	Total . . .					628	266°	94°	—	360

Revolutions per piece $\frac{62 \times 360}{266} = 850$

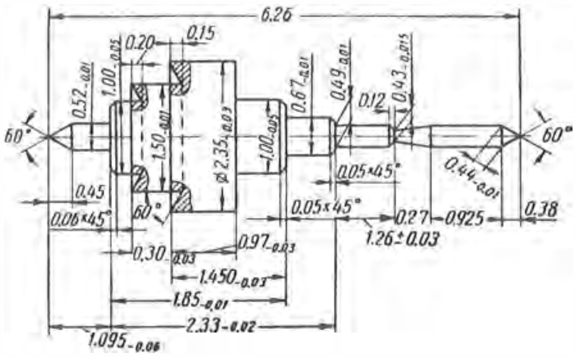
Production rate, pieces per minute $A = 5550 : 850 = 6.6$

Setup calculation
Sheet A-2

Part No.	Part name	Material	Cutting speed
K-26-8	Central pinion	U7AV steel	37 m/min

Cam lever ratio	Headstock	Rocker	Tools Nos 3, 4, 5	Spindle rpm	5550
	3:1	10:1	1:1 2:1 2:1	Production rate	5.7 pieces per minute

Device for frontal plunging with lever arm ratio 1:1



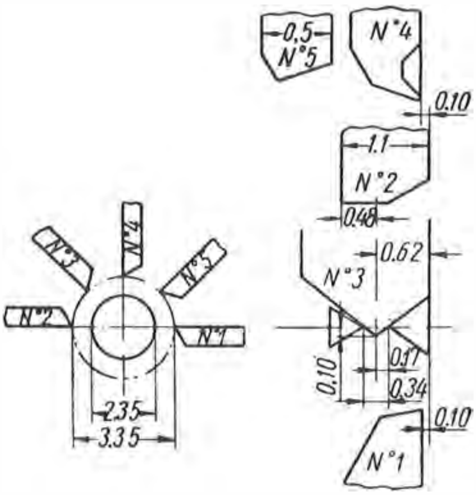
Setup calculation
Sheet A-2

Order of operations	Designation of operations	Headstock and tool travel	Cam lever ratio	Rise or drop on the cam	Feed per spindle revolution	Number of working revolutions	Cam rotation, degrees, for machining	Cam rotation, degrees, for idle move-ment	Camshaft position, degrees from	Camshaft position, degrees to
1st	Release collet . . .	—	—	—		—	—	10	0	10
2nd	Retract headstock .	6.26 + 0.34 = = 6.6 mm	3	19.8	—	—	—	12	10	22
3rd	Close collet	—	—	—	—	—	—	15	22	37
4th	Retract No. 3 . . .	1.175 + 0.1 + + 0.5 = 1.775	1	1.775	—	—	—	(9)	37	46
5th	Advance No. 1 . .	1.175 + 0.5 — — 0.26 = 1.415	10	14.15	—	—	—	9	37	46
6th	Advance headstock	0.1 + 0.645 = = 0.745	3	2.285	0.008	93	33	—	46	79
7th	Dwell	—	—	—	—	—	—	2	79	81
8th	Retract No. 1 . . .	$\frac{0.88 - 0.52}{2} = 0.18$	10	1.8	—	—	—	3	81	84
9th	Retract No. 1 . . . Advance headstock	0.06 0.06	10 3	0.6 0.18	0.005 —	12 (12)	5 (5)	— —	84 84	89 89
10th	Advance headstock	0.04	3	0.12	0.005	8	4	—	89	93
11th	Dwell	—	—	—	—	—	—	2	93	95
12th	Retract No. 1 . . .	0.25	10	2.5	—	—	—	3	95	98
13th	Advance headstock	0.30	3	0.9	0.015	20	7	—	98	105
14th	Dwell	—	—	—	—	—	—	2	105	107
15th	Retract No. 1 . . .	0.925	10	9.25	—	—	—	6	107	113
16th	Approach No. 4 .	0.925	2	1.85	—	—	—	(4)	109	113
17th	Advance headstock (recess ϕ 1.50) .	0.25	3	0.75	0.020	12	5	—	113	118
18th	Dwell	—	—	—	—	—	—	2	118	120
19th	Retract headstock	0.25	3	0.75	—	—	—	3	120	123
20th	Retract No. 4 . . .	0.925	2	1.85	—	—	—	3	123	126
21st	Approach recessing-attachment tool	—	—	—	—	—	—	(7)	119	126
22nd	Recess ϕ 1 mm . .	0.4	1	0.4	0.020	20	7	—	126	133
23rd	Dwell	—	—	—	—	—	—	2	133	135
24th	Retract recessing-attachment tool	—	—	—	—	—	—	3	135	138
25th	Advance headstock	0.97 + 1.1 — — 0.1 = 1.97	3	5.91	—	—	—	5	138	143
26th	Advance No. 2 . .	0.4	10	4	—	—	—	(4)	138	143

Sheet A-2 (cont'd)

Part No.	Part name			Material	Cutting speed	
K-26-8	Central pinion			U7AV steel	37 m/min	
Cam lever ratio	Headstock	Rocker	Tools Nos 3, 4, 5		Spindle rpm	5550
	3:1	10:1	1:1 2:1 2:1		Production rate	5.7 pieces per minute

Device for frontal plunging with lever arm ratio 1:1



Sheet A-2 (cont'd)

Order of operations	Designation of operations	Headstock and tool travel	Cam lever ratio	Rise or drop on the cam	Feed per spindle revolution	Number of working revolutions	Cam rotation, degrees, for		Camshaft position, degrees	
							machining	idle movement	from	to
27th	Advance No. 2 . .	$\frac{2.35}{2}+0.1-\frac{1.00}{2}=0.775$	10	7.75	0.010	78	28	—	143	171
28th	Dwell	—	—	—	—	—	—	2	171	173
29th	Advance headstock	1.450 − 0.97 − − 0.05 = 0.430	3	1.290	0.015	29	10	—	173	183
30th	Advance headstock	0.05	3	0.15	—	—	—	—	—	—
	Advance No. 2 . .	0.05	10	0.5	0.005	10	4	—	183	187
31st	Advance No. 2 . .	$\frac{0.90-0.67}{2}=$ = 0.115	10	1.15	0.008	15	6	—	187	193
32nd	Dwell	—	—	—	—	—	—	2	193	195
33rd	Advance headstock	2.33 − 1.85 − − 0.05 = 0.43	3	1.29	0.015	28	10	—	195	205
34th	Advance headstock	0.05	3	0.15	—	—	(4)	—	205	209
	Advance No. 2 . .	0.05	10	0.5	0.005	10	4	—	205	209
35th	Advance No. 2 . .	0.04	10	0.4	0.003	13	5	—	209	214
36th	Dwell	—	—	—	—	—	—	2	214	216
37th	Advance headstock	1.26	3	3.78	0.012	110	40	—	216	256
	Advance No. 2 . .	0.025		Turning cones of small slope						
38th	Dwell	—	—	—	—	—	—	2	256	258
39th	Retract No. 2 . . .	1	10	10	—	—	—	6	258	264
40th	Approach No. 5 . .	1.445	2	2.89	—	—	—	(6)	258	264
41st	Plunge No. 5 . . .	0.015	2	0.03	0.005	5	3	—	264	267
42nd	Dwell	—	—	—	—	—	—	2	267	269
43rd	Retract No. 5 . . .	1.460	2	2.92	—	—	—	3	269	272
44th	Approach No. 2 .	1	—	—	—	—	—	(6)	269	272
45th	Advance No. 2 . .	0.025		Turning cones of small slope						
	Advance headstock	1.195	3	3.585	0.012	100	37	—	272	309
46th	Advance headstock	0.38	3	1.14	0.01	38	13	—	309	322
47th	Retract No. 2 . . .	1.455	10	2.91	—	—	—	10	322	332
48th	Retract headstock	0.43 + 0.48 = = 0.91	3	—	—	—	—	3	322	335
49th	Approach No. 3. .	1.405	1	1.405	—	—	—	3	335	338
50th	Advance headstock	0.60	3	1.80	0.010	60	22	—	338	360
	Advance No. 3 . .	0.37	1	0.37	—	(60)	—	—	338	360
	Total . . .	—	—	—	—	661	243	117	—	360

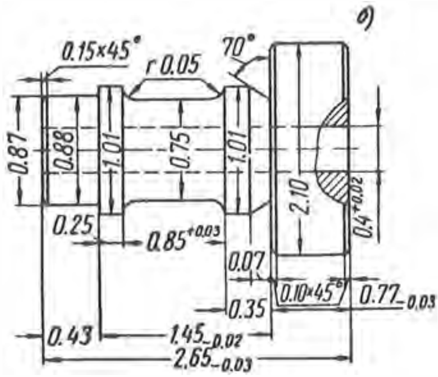
$\frac{661\times 360}{243}$ = revolutions

Production rate $A = \frac{5550}{980} = 5.7$ pieces per minute

Setup calculation
Sheet A-3

Part No.	Part name	Material	Cutting speed
K-26-12	Cannon pinion	U10A	33 m/min

Cam lever ratio	Headstock	Rocker	Tool No.4	No.5	Spindle rpm	5000
	2:1	3:1	2:1	2:1	Production rate	6.4 pieces per minute



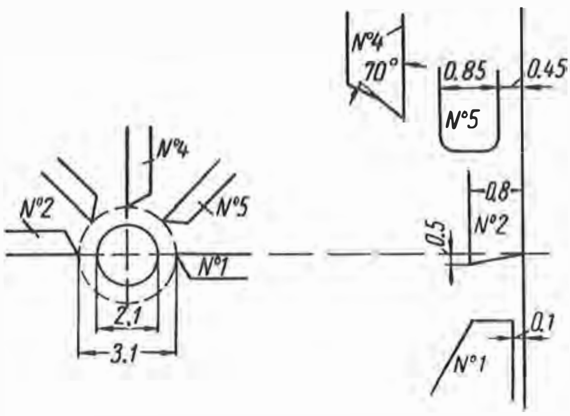
Setup calculation
Sheet A-3

Order of operations	Designation of operations	Headstock and tool travel	Cam lever ratio	Rise or drop on the cam	Feed per spindle revolution	Number of working revolutions	Cam rotation, degrees, for		Camshaft position, degrees	
							machining	idle movement	from	to
1st	Release collet . .	—	—	—	—	—	—	10	0	10
2nd	Retract headstock	2.65 + 0.8 = = 3.45	2:1	6.90	—	—	—	8	10	18
3rd	Close collet . . .	—	—	—	—	—	—	15	18	33
4th	Retract No. 2 . .	2.05	3:1	6.15	—	—	—	6	33	39
5th	Approach centering tool	—	—	—	—	—	—	(6)	33	39
6th	Advance headstock	0.1 + 0.2 = = 0.3	2:1	0.6	0.010	30	12	—	39	51
7th	Dwell	—	—	—	—	—	—	2	51	53
8th	Retract headstock	0.3	—	—	—	—	—	3	53	56
9th	Retract centering tool	—	—	—	—	—	—	10	56	66
10th	Switch-attachment to drill spindle .	—	—	—	—	—	—	20	66	86
11th	Approach drill . .	—	—	—	—	—	—	10	86	96
12th	Approach No. 1 .	0.5 + 1.05 — — 0.185 = = 1.365	3:1	4.095	—	—	—	(6)	90	96
13th	Advance headstock	0.1 + 0.15 = = 0.25	2:1	0.50	0.008	30	12	—	96	108
14th	Retract No. 1 . . .	0.1 + 0.15 = = 0.25	3:1	0.75	0.008	(30)	—	—	96	108
15th	Retract No. 1 . . .	0.005	3:1	0.015	—	57	(25)	—	108	133
16th	Advance headstock	0.28	2:1	0.56	0.005	57	25	—	108	133
17th	Dwell	—	—	—	—	—	—	2	133	135
18th	Retract No. 1 . . .	0.065	3:1	0.195	—	—	—	3	135	138
19th	Advance headstock	1.45	2:1	2.9	0.015	100	43		138	181
20th	Dwell	—	—	—	—	—	—	2	181	183
21st	Retract No. 1 . . .	$\frac{2.1-1.01-0.2}{2.0} = 0.445$	3:1	1.335	0.008	55	25	—	183	208
22nd	Retract No. 1	0.1	3:1	0.3	0.010	10	5	—	208	213
23rd	Advance headstock	0.1	2:1	0.20	—	—	(5)	—	208	213
24th	Retract No. 1 . . .	0.50	3:1	1.50	—	—	—	3	213	216
25th	Approach No. 5 .	$\frac{2.10-1.01}{2} + 0.4 = 0.945$	2:1	1.890	—	—	—	(3)	213	216

Sheet A-3 (cont'd)

Part No.	Part name	Material	Cutting speed
K-26-12	Cannon pinion	U10A	33 m/min

Cam lever ratio	Headstock	Rocker	Tool No. 4	No 5	Spindle rpm	5000
	2:1	3:1	2:1	2:1	Production rate	6.4 pieces per minute



Sheet A-3 (cont'd)

Order of operations	Designation of operations	Headstock and tool travel	Cam lever ratio	Rise or drop on the cam	Feed per spindle revolution	Number of working revolutions	Cam rotation, degrees, for		Camshaft position, degrees	
							machining	idle movement	from	to
26th	Plunge No. 5 . . .	0.230	—	0.46	0.005	43	18	—	216	234
27th	Dwell	—	—	—	—	—	—	2	234	236
28th	Retract No. 5 . . .	1.175	—	2.35	—	—	—	3	236	239
29th	Approach No. 4 .	0.945	2: 1	1.890	—	—	—	3	239	242
30th	Plunge No. 4 . . .	0.1 + 0.025 = = 0.125	2	0.35	0.008	15	10	—	242	252
31st	Dwell	—	—	—	—	—	—	2	252	254
32nd	Retract No.4 . . .	1.070	—	2.14	—	—	—	2	254	256
33rd	Advance headstock	1.27	—	2.54	—	—	—	4	256	260
34th	Approach No. 2 .	0.50	—	1.50	—	—	—	3	260	263
35th	Advance headstock	0.1	—	0.2	0.005	20	10	—	263	273
36th	Advance No. 2 . .	0.1	—	0.3	—	—	(10)	—	263	273
37th	Advance No. 2 . .	1.45	—	4.35	0.008	180	87	—	273	360
	Total	—	—	—	—	540	247°	113°	—	360°

$$n = \frac{540 \times 360}{247} = 790 \text{ revolutions per piece}$$

Production rate A = 5000: 790 $\approx$ 6.4 pieces per minute

	Designation of operations	Headstock and tool travel	Cam lever ratio	Rise or drop on the cam	Feed per spindle revolution	Number of working revolutions	machining	idle movement	from	to
	Approach drill . . .	—	—	—	—	—	—	10	86	96
	Dwell	—	—	—	—	—	—	10	96	106
	Advance drill . . .	0.85	1: 1	0.85	—	112	—	—	106	218
	Retract drill	—	—	—	—	—	—	12	218	230

Cam marking and manufacture. Cams are marked in a special device (Figure 33). The cam is held on the vertical mandrel of the circular table (1). of the device.

The cam is center-punched along the outer profile by the center punch (2), mounted in the bracket (3) of the plunger (4). The plunger can move in the radial direction, and the value of its displacement is measured on the scale (5). The idle-movement curves are laid out by means of the template (6).

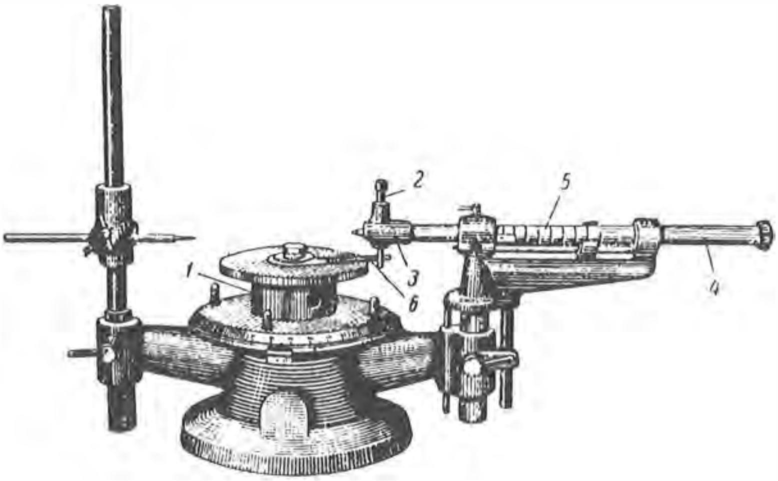


FIGURE 33. Device for cam layout

Cams are manufactured in three operations. The first operation consists in the drilling of holes along the layout contour and the removal of the excess metal. The second operation is the milling of the cam in a special machine with an allowance of 0.3 – 0.4 mm. The third operation involves bringing the cam to shape on a special machine*.

The cam radii are measured in a device with a built-in indicator. Actually, the differences between the two radii corresponding to the beginning and the end of a curve are measured, and not the radii themselves. As this difference is equal to the rise or drop on the cam, it must be very accurate, any inaccuracy in the manufacture of the cam profile being transferred to the product.

The smallest radii on the cam, if extending over considerable angles of rotation, are reduced by 1 mm relative to their calculated value, so that the follower will not touch the cam when passing through the arc of this radius, its lever being supported on a correspondingly adjusted special stop.

This also makes it possible to prevent the follower from falling into the assemblv slots on the cams for tools Nos 3, 4, 5,

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* See illustrated catalogue of Glavchasprom MM and P.

The specified high accuracy of geometrical shape and high surface-finish quality are achieved by virtue of the accuracy of the screw machine itself and by the use of high-quality tools and attachments.

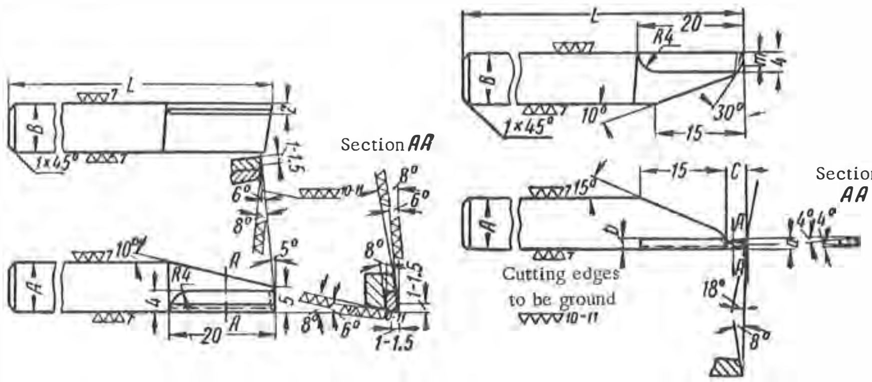
Tools and implements used with Swiss-type automatic screw machines include prismatic tools with carbide inserts, twist drills (left-hand), chaser dies and taps, slotting cutters, and chucking collets.

Tools. The tools must satisfy rigid requirements relative to the surface quality of the cutting edges and the strict paralleleity and perpendicularity of the tool-shank planes. The dimensions and shapes of tools Nos 1 and 2 are given in Table 16.

The dimension C is specified in the tool order.

TABLE 16

Dimensions and shape of tools Nos 1 and 2, mm



A	B	L	A	B	L
6	6	80	10	10	100
8	12	100	10	16	100

The cutting edges of the tools are brought to a class 10 or 11 surface-finish quality on S-194 machines using boron carbide powders and diamond disks (see Chapter IX). The tool edges are first ground by boron carbide and then polished on a diamond disk. The grinding gives the tool edges a dull surface which influences negatively the chip flow and favors heating of the tip. The maximum blunting allowed on edges of journal-turning tools is r = 0.01 mm, and therefore the carbide tip must be of fine-grained structure (3.5 to 5 μ grain size). Carbide tips are made of VK6-VK8 alloy (tungsten-cobalt) and are brazed to the shank using a copper solder.

The tool shank has strictly parallel and perpendicular edges which ensure the correct positioning of the tool in the slide. The width of the cut-off tool is especially important. The chips removed by the cut-off tool in the manufacture of certain watch parts constitute 140 to 180% of the part weight. The cut-off tool width must consequently be reduced to a minimum, but this reduction must not increase the tool vibrations, as this would impair the surface quality of the part. Recommended cut-off tool widths are given in Table 17.

TABLE 17

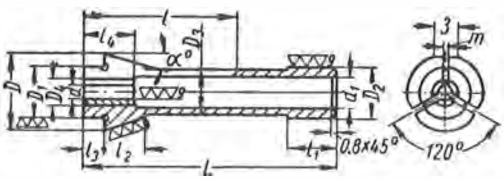
Cut-off tool widths

Bar stock diameter, mm	Tool width, mm	
	steel	brass
Up to 2	0.7	0.7
2.1 – 4	0.9	0.8
4.1 – 6	1.1	0.9
6.1 – 8	1.2	1.0
8.1 – 10	1.5	1.2

Collets. The dimensions and shape of the collets used in the Swiss-type automatic screw machines are given in Table 18. The collets are made of U8A steel. Requirements relative to the collet include the correct gripping of the bar or tool and concentricity of the hole with the outer guide surfaces; the closing cone and the cylindrical surface. According to specifications, the run-out on these surfaces must not exceed 0.01 mm. Run-out is checked at a distance of 5 – 10 mm from the collet grip by means of a mandrel held in the collet.

TABLE 18

Dimensions and shape of collets for Swiss-type automatics, mm



D	D_1	D_2	D_3	d_1	l	l_1	l_2	l_3	L	α°	Machine let-through(max. bar diameter)
12	8	8	7.5	5	21	8	6	3 5	41	15	4 mm
16	10	10	9.5	7	35.5	10	7	5.5	47.5	15	6 "
19	13	13	12.6	9.5	45	18	10	6	64	15	8 "
21	14.5	15	14.5	10.5	45	18	10	6	64	15	10 "

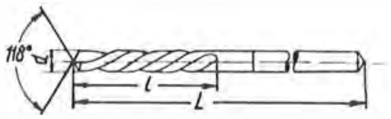
Notes: 1. Admissible radial run-out for d, 0.010 mm.
2. Dimensions d, l_4, D_4, m to be taken from tables.

The diameter of the collet hole is equal to the nominal diameter of the bar with the tolerance of class 2 accuracy suitable for a close running fit. The use of collets having slightly different dimensions is not recommended as an additional run-out appears as a result of the incorrect gripping of the bar stock and the collet rapidly loses its spring properties. The collet has brazed carbide inserts which increase its durability 4-5 times. Collets with carbide inserts are slotted by means of diamond cutting disks.

Twist drills. Left-hand twist drills are used on Swiss-type automatics. The types and dimensions of the twist drills most frequently used in watch production are given in Tables 19 and 20.

TABLE 19

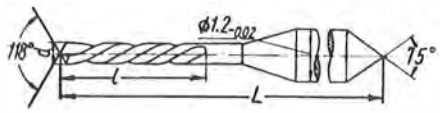
Dimensions of straight-shank twist drills with ground flutes, mm



Drill diameter		l	L
nominal dimension	tolerance		
0.025—0.30	—0.008	3	18
0.32—0.40	—0.010	4	20
0.42—0.50	—0.010	5	22
0.52—0.60	—0.010	6	24
0.62—0.70	—0.012	7	26
0.72—0.80	—0.012	8	28
0.82—1.00	—0.012	10	30

TABLE 20

Dimensions of twist drills with ground flutes and oversize straight shanks, mm



Drill diameter		l	L
nominal dimension	tolerance		
0.10—0.20	—0.006	1.5—2.5	15
0.21—0.30	—0.008	2.5—3	15
0.32—0.40	—0.010	4	18
0.42—0.50	—0.010	5	20
0.52—0.60	—0.010	6	22
0.62—0.70	—0.012	7	24
0.72—0.80	—0.012	7	24
0.82—1.00	—0.012	10	28

Drills with oversized shanks make it possible to reduce the number of collet dimensions. Because of the small diameters of the drills, the helical flutes, having a particular contour, are ground from the hardened blank /12/

The tolerance on the working diameter is according to accuracy class 2 a* of GOST 3047-54. The drills are made of type R18 high-speed steel with a hardness R_C= 59 to 62.

U10A-U12A steel is not used for drills as the drills are heated by the grinding wheel (when the flutes are ground), and this would considerably reduce the hardness of drills made of these steels.

Taps. Watch mechanisms use right-hand, and sometimes left-hand, threads of diameters from 0.3 to 2.6 mm. The thread-profile angle is 50°, for threads of 0.3 – 0.9 mm diameter, according to GOST 3196-46, and 60° for watch threads of larger diameters, according to GOST 7217. The 50° profile has several advantages over the generally used 60° profile for small diameters. The strength of the thread increases as a result of the increase

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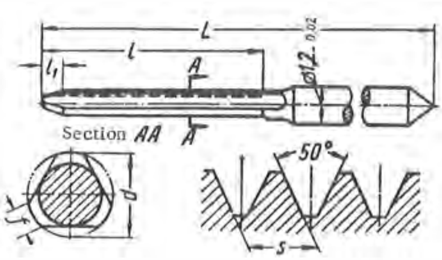
* [A 1st accuracy class fit corresponds to an extra fine fit, a 2nd accuracy class fit to a fine fit, a 3rd accuracy class fit to a plain fit, and a 4th accuracy class fit to a rough fit.]

in its depth and the thread wear rate decreases as a result of the increase in the flank area. Among the shortcomings of 50° threads is a certain weakening of the screw or tap body as a result of the decrease in the root diameter.

The over-all length and the threading length of the taps used for threading 0.3 – 0.9 mm diameter threads are different from those generally accepted (see Table 21).

TABLE 21

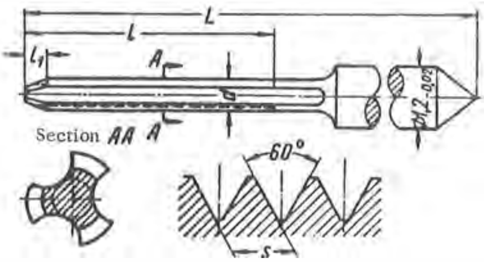
Dimensions and shape of triangular taps, mm



d	s	L	l	l_1	f
0.3	0.075	16.8	2.6	0.5	0.1
0.35	0.075	16.8	2.6	0.5	0.12
0.40	0.100	18.8	3.5	0.6	0.15
0.45	0.100	18.8	3.5	0.6	0.17
0.50	0.125	20.9	4	0.75	0.2
0.55	0.125	20.9	4	0.75	0.22
0.60	0.150	20.9	5	0.85	0.25
0.70	0.175	20.9	6	1	0.25
0.80	0.200	23.0	7	1.2	0.30
0.90	0.225	23.0	7	1.3	0.30

TABLE 22

Dimensions of three-flute taps, mm



d	s	L	l	l_1	f
1	0.25	27.7	8	1.5	2
1.2	0.25	27.7	8	1.5	2
1.4	0.30	30	10	1.75	2
1.7	0.35	32	12	2	2
2.0	0.40	35	14	2.3	3
2.3	0.40	35	14	2.3	3
2.6	0.45	38	16	2.5	3

Triangular taps track reliably into the hole, have a small cutting-lip width, and are stronger than taps of the usual shape. Their shortcoming lies in their large negative rake angles, as much as 40° at the major diameter, and 70° at the minor diameter. Cutting is replaced to a considerable extent by scraping when these taps are used, and this requires an additional effort.

Triangular taps have insufficient clearances for chip removal and such taps are therefore not used for threading holes of a diameter larger than 1 mm in brass and steel, nor holes with a depth greater than $1.5d$.

Three-flute taps are used for threads of diameter larger than 1.0 mm and depth more than $1.5d$. The dimensions of these taps are given in Table 22.

The three-flute taps have zero rake angles and this gives considerably improved cutting conditions as compared with the triangular taps.

The flutes also provide sufficient chip space.

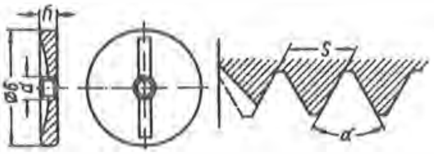
The body section of three-flute taps is somewhat weakened and it is more difficult to mill the flutes in these taps than in the triangular taps. Three-flute taps are made from U10A – U12A steel.

Chaser dies. Three standard types of chaser dies are used in watch production: round, nonadjustable, thread-forming tools without chip spaces for cutting threads of 0.3 – 1.2 mm diameter; tubular adjustable chasing dies with chip spaces for cutting threads of 0.3 – 1.7 mm diameter; and round, nonadjustable dies with chip spaces for cutting threads of 1.0 to 2.6 mm diameter.

The round, nonadjustable dies without chip spaces are flat disks with tapped holes (see Table 23).

TABLE 23

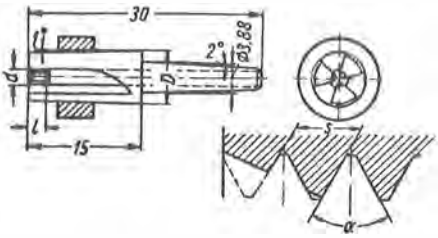
Dimensions of round dies without chip spaces, mm



d	s	h	d	s	h
0.3	0.075	0.35	0.60	0.150	0.60
0.35	0.075	0.35	0.70	0.175	0.60
0.40	0.100	0.35	0.8	0.200	0.60
0.45	0.100	0.35	0.9	0.225	0.70
0.50	0.125	0.40	1.0	0.250	0.90
0.55	0.125	0.40	1.2	0.250	0.90

TABLE 24

Dimensions of tubular dies, mm



d	s	D	l	d	s	D	l
0.30	0.075		0.5	0.70	0.175		1
0.35	0.075		0.5	0.80	0.200	6	1.4
0.40	0.100		0.5	0.90	0.225		1.4
0.45	0.100	5	0.5	1.00	0.250		1.4
0.50	0.125		0.5	1.2	0.250	6.5	1.6
0.55	0.125		1	1.4	0.300		1.6
0.60	0.150		1	1.7	0.350		2

The die hole is chamfered at both ends and its thickness must not exceed three thread pitches. The depth of the chamfer is 0.75**s** and the cutting and calibrating portions of the die are equal in length.

An increase in the thickness of the die leads to the swift worsening of the threading conditions, to jamming of the part in the die and to breaking off of the part.

A notch is cut on the end plane of the die to ameliorate the conditions of thread formation. The service life of these dies is not long (400 to 600 threads), but their manufacture is simple. The blanks for them are stamped from a strip.

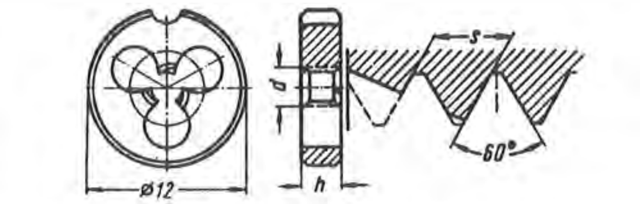
The tubular, adjustable dies are mainly used for threading in specialized automatic machines. Their dimensions are given in Table 24.

Tubular dies have three cutting lips with positive rake angles. The threads are cut, and not formed as by the first type of die. The dies are adjustable, which is particularly important when the mechanical properties of the bar stock are not uniform. When the lips dull they can be resharpened by grinding the faces, and if the part being threaded breaks it can be removed from the die by removing the adjusting ring and forcing the lips apart. A die without chip spaces must be discarded in such a case. The service life of tubular chasing dies is 5-6 times longer than that of the forming dies, but their production requires several times more labor and materials. The adjustable chasing dies are better than the forming dies for use in mass production.

Round dies, nonadjustable but with chip spaces, are used for cutting threads of 1 mm diameter and larger. Their advantage relative to the dies without chip spaces lies in the presence of three cutting faces with positive rake angles and with windows for chip removal (see Table 25).

TABLE 25

Dimensions of round dies, mm



d	s	h
1	0.25	2.0
1.2	0.25	2.0
1.4	0.30	2.5
1.7	0.35	2.5
2.0	0.40	3.0
2.3	0.40	3.0
2.6	0.45	3.0

Round dies with chip spaces are more expensive to produce than are those without chip spaces; however, they can be resharpened by grinding the cutting faces. The dies are manufactured from U12A and 9KhS, steels.

Slotting cutters. Table 26 gives the dimensions of the slotting cutters, made of U10A, U12A, 9KhS steels, used for slotting screw heads and cutting small slots in bushings and other parts.

Measuring instruments. The outer diameters and lengths of the machined parts are measured by micrometers of special design. Dimensions with tolerances of 0.02 mm and larger are measured by the horizontal L-23 micrometer with divisions of 0.01 mm on the barrel and range from 0 to 15 mm (Figure 34).

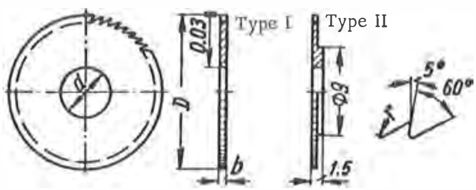
Dimensions with tolerances between 0.003 and 0.03 mm are measured by means of the combined instrument K-6, consisting of an indicator with scale divisions of 0.001 mm and range ± 0.03 mm, and a micrometer head with scale divisions of 0.01 mm, and range 0 to 10 mm (Figure 35).

The indicator and the micrometer are mounted on the same base. The micrometer serves for establishing the nominal dimension (length or diameter), and the indicator for measuring within the tolerance range. The convenience of this instrument lies in the fact that dimensions from 0 to 10 mm can be measured on it to a high degree of accuracy.

TABLE 26

Dimensions of slotting cutters, mm

For $b \leq 0.3$



D	d nominal	d tolerance	b nominal	b tolerance	z	r	D	d nominal	d tolerance	b nominal	b tolerance	z	r
$12_{-0.24}$	5	+0.013	0.10 0.12 0.15 0.18 0.20	+0.01 +0.01 +0.015 +0.015 +0.015	56	0.1	$20_{-0.28}$	6	+0.013	0.15 0.20 0.30	+0.015 +0.02 +0.02	70	0.1
										0.40 0.50 0.60	+0.02 +0.02 +0.02	64	0.2
$16_{-0.24}$	5	+0.013	0.15 0.18 0.20 0.25 0.30	+0.015 +0.015 +0.02 +0.02 +0.02	64	0.1	$24_{-0.28}$	8	+0.016	0.30 0.40	+0.02 +0.02	80	0.1
										0.50 0.60	+0.02 +0.02	70	0.2
			0.35 0.40 0.45 0.50 0.60	+0.02 +0.02 +0.02 +0.02 +0.02	56	0.2	$30_{-0.28}$	8	+0.016	0.30 0.40	+0.02 +0.02	80	0.1
										0.50 0.60	+0.02 +0.02	80	0.2

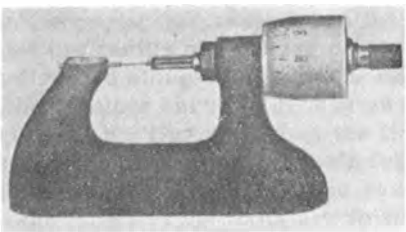


FIGURE 34. Horizontal micrometer with scale divisions of 0.01 mm, and range of 0 to 15 mm

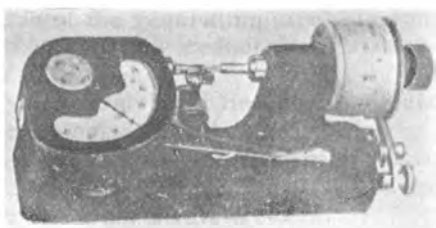


FIGURE 35. K-6 instrument with indicator scale divisions of 0.001 mm, and micrometer scale divisions of 0.01 mm

Internal diameters are measured by means of plug gages. A set of such gages, with intervals of 0.0025 mm between them, serve for measuring holes with diameters between 0.05 and 0.3 mm. The accuracy of these gages is ± 0.0005 mm. The gage (1) is inserted in the bushing (2) and is supported in the handle (3) (Figure 36).

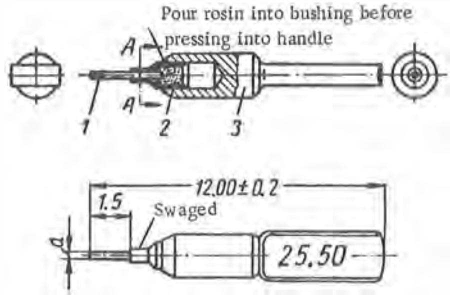


FIGURE 36. Plug gage:

1—gage; 2—bushing; 3—handle.

FIGURE 37. Set of gages (100 pieces)

The gage diameter is written on the handle in hundredths of a milli-meter (a gage of 0.2550 mm diameter is designed 25.50). The gages are arranged in sets of 100 (Figure 37). The gages can serve as standards when adjusting indicators and micrometers for relative measurements.

Ring and plug thread gages are used for checking external and internal threads, respectively.

The surface-finish quality of machined parts is determined, under plant conditions, by means of a microscope with a magnification of 16× to 32×.

Chapter V

MILLING THE TEETH OF GEAR WHEELS, PINIONS, AND CLUTCHES

Toothed transmissions in pocket- and wristwatches transmit moment from the mainspring to the balance and balance spring system, rotation from the escape wheel to the hands, and force from the human hand to the winding mechanism for periodically winding the mainspring.

The transmission ratio between the barrel arbor and the escape wheel can be as much as 1:5400, and the amount of energy stored in the wound mainspring is small. The moment transmitted to the escape wheel is therefore very small: in the case of the "Zarya" brand of ladies' wristwatches the moment transmitted to the escape wheel is M_{min} = 0.030 gmm.

The gear transmissions in watches must, therefore, have a high efficiency; that is, the friction losses both between the meshing teeth and in the bearings must be at a minimum. In order to reduce the dimensions of watches, gear modules of 0.07–0.30 mm and driven wheels (pinions) having 6–12 teeth are used.

These basic requirements are the determining factors which lead to the use in watches of a modified cycloidal gear-tooth form, which we will refer to as "watch gearing".

The tooth contour of the wheels and pinions of watch mechanisms can, however, have an epicycloidal, hypocycloidal or involute form.

The epicycloid curve is generated by rolling a generating circle I on a base circle II, the center of the generating circle lying outside the base circle (Figure 1, a). Any point A on the rolling circle describes an epicycloidal arc O_1A.

The hypocycloid curve is generated by rolling a generating circle II on a base circle I, the center of the generating circle lying inside the base circle (Figure 1,b). Any point A on the rolling circle describes a hypocycloidal arc O_1A.

In the particular case, when the radius of the generating circle is equal to half the radius of the base circle, the hypocycloid reduces to a straight line directed along a base circle radius.

The involute curve is generated by rolling a straight line on a base circle (Figure 1,c). The point A on the line describes an involute arc O_1A.

In cycloidal gearing the tooth face is constituted by an epicycloidal arc, and the tooth flank is a straight radial line (Figure 2). In involute gearing both the face and the flank are formed by a single involute curve.

The difference between watch gearing and ordinary cycloidal gearing is that in watch gearing the epicycloids are replaced by circular arcs. The circular arc selected is similar to the epicycloid (Figure 3) in the case of gear wheels, and differs considerably from it in pinions (Figure 4).

The tooth tip form A is a semicircle of radius equal to half the tooth thickness. The form C consists of circular arcs of radius equal to the tooth thickness. Form B consists of circular arcs of radius equal to 2/3 the tooth thickness. Form A is used relatively rarely and then for pinions with more than 12 teeth. Form C is used for pinions with 6 or 7 teeth and is called the ogival full-depth tooth form. Form B is widely used for pinions with $z > 7$ and is called the ogival stub-tooth form.

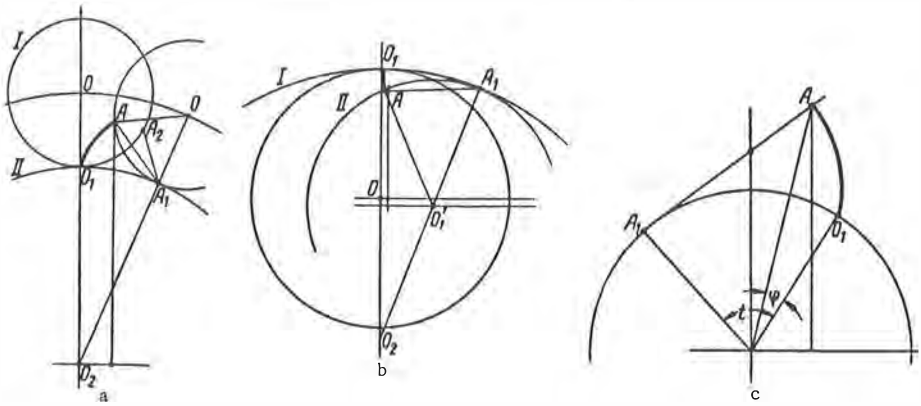


FIGURE 1. Generating tooth forms:

a–epicycloidal; b–hypocycloidal; c–involute.

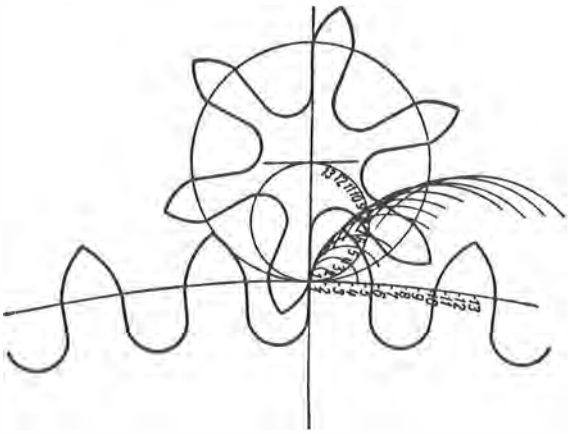


FIGURE 2. Cycloidal gearing

The reason for the replacement of the epicycloids by circular arcs in gear-wheel teeth lies in the difficulty of producing milling cutters of epicycloidal contour.

In the case of pinion teeth the main reason for the replacement of the epicycloid is the need to reduce the angle of approach, which in turn makes it possible to increase the efficiency of the gear transmission.

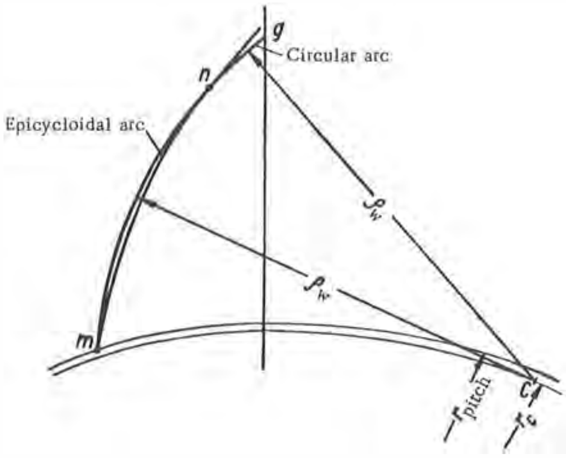


FIGURE 3. Replacement of the epicycloidal arc by a circular arc

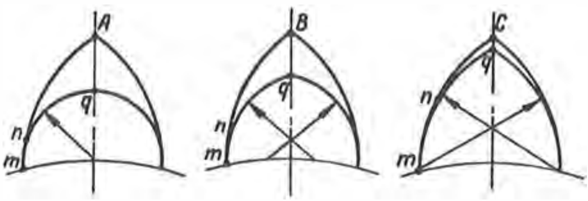


FIGURE 4. Profiles of pinion teeth tips

The line of action of a meshed pair is the locus of the points of contact of the two meshing contours on a given plane.

In the case of involute teeth the line of action is the straight line passing through the pitch point P and tangent to the two base circles (Figure 5, a).

The segment AB is the active portion of the line of action.

In the case of cycloidal tooth contours the line of action consists of two arcs of the generating circles $AP + PB$, meeting at the pitch point P (Figure 5, b).

The follower face and the driver flank are in action till the line of centers O_1O_2 is reached, while the driver face and the follower flank are in action beyond the line of centers.

The angles through which the driver and follower teeth move from the beginning of their contact to the line of centers are called *the angles of approach*, while the angles from the line of centers to the end of contact are *the angles of recession*. In the case of cycloidal gearing the angles of approach are α_1 and α_2 and the angles of recession are β_1 and β_2 (Figure 5, b).

The sum of the angles of approach and recession for each wheel must be equal to or larger than its angular pitch: $\alpha + \beta \geqslant \frac{360°}{z}$, where z is the number of teeth on the wheel.

The values of the angles of approach and recession for the basic gear pairs of watch mechanisms are given in Table 1. If these gear pairs had teeth with involute contours, the angles of approach would have been between 20 to 25°. The advantage of the watch gearing over involute tooth form gearing is clear considering the fact that the friction losses decrease with decreased angle of approach.

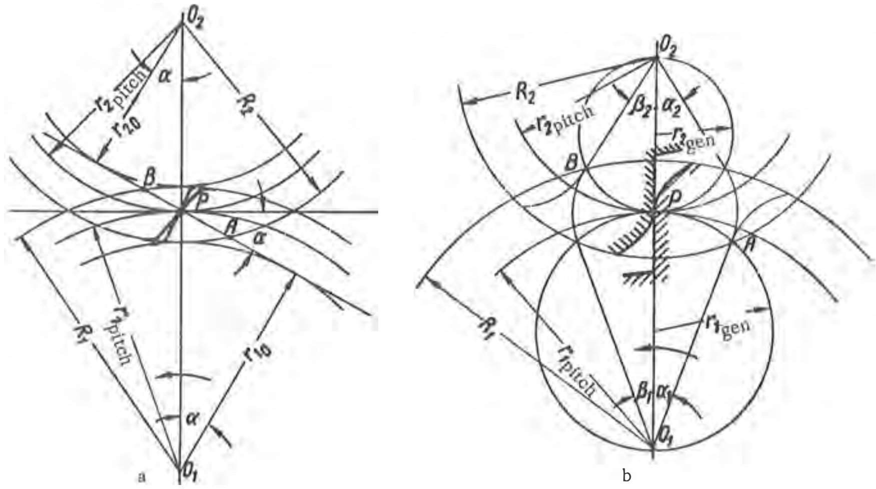


FIGURE 5. Line of action:

a–involute profiles; b–cycloidal profiles.

TABLE 1

Angles of approach and recession in watch gearing (shortened)

Number of teeth: wheel — z_w; pinion — z_p	Angular pitch of pinion	Angle of approach	Angle of recession	Pinion tooth form (acc. to Fig.4)
$z_w = 60$ $z_p = 6$	60°	17°44′13″	42°15′47″	*C*
$z_w = 70$ $z_p = 7$	51°25′43″	11°30′28″	39°55′15″	*C*
$z_w = 60$ $z_p = 8$	45°	7°23′40″	37°36′20″	*B*
$z_w = 64$ $z_p = 8$	45°	7°17′30″	37°42′30″	*B*
$z_w = 80$ $z_p = 8$	45°	6°59′5″	38°0′55″	*B*
$z_w = 75$ $z_p = 10$	36°	1°20′7″	34°39′53″	*B*
$z_w = 80$ $z_p = 10$	36°	1°14′12″	34°45°48″	*B*

In watch gearing the line of action will deviate from the theoretical curve AB (Figure 5, b) at those sections where the circular arcs do not coincide with the epicycloids. This deviation disturbs the transmission ratio of the meshing pairs (within the limits of one pitch), and in consequence the moment transmitted is altered and the accuracy is disturbed. This is the main shortcoming of watch gearing.

In order to reduce this deviation to a minimum, the active portion of the wheel tooth profile $m — n$ (see Figure 3) and of the pinion tooth profile (Figure 4, shape C), are made to approximate the epicycloid as closely as possible.

The basic parameters of watch gearing are given in Appendix 2 (Standards of the Glavchasprom (Watch Industry Center)).

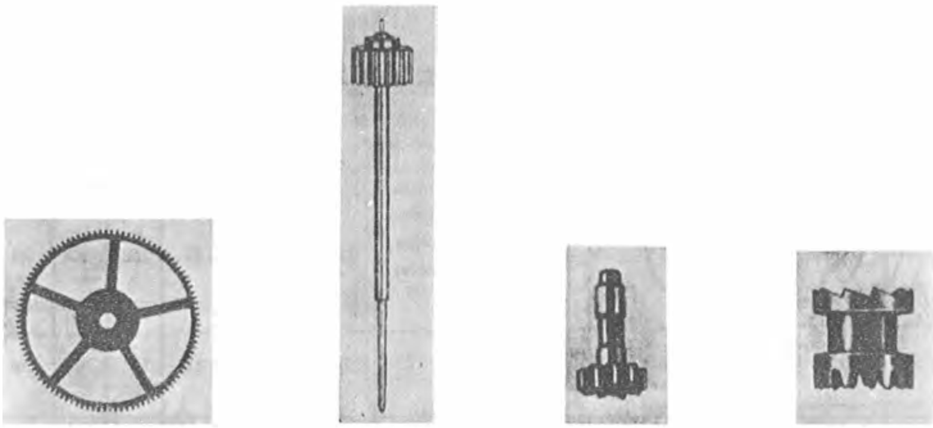
The tolerance on the center distance must be narrower for cycloidal and watch gears than for involute gears.

Deviations in the center distance will produce, in the case of cycloidal or watch gearing, a contact either between two hypocycloids or two epicycloids and this obviously will disturb the transmission ratio. In involute gears the transmission ratio is not affected by such deviations.

The influence of radial wheel run-out or an increase or decrease in its diameter is similar to that of a deviation in the center distance. Accordingly, narrow tolerances are fixed for these parameters.

Jewel bearings are used in watches in order to reduce the friction losses in the bearings and to increase the efficiency of the gear transmission.

Photographs of a wheel, pinions, and a claw clutch are given in Figure 6.



a b c d

FIGURE 6. Toothed watch parts

a–chronograph wheel; b–third-wheel pinion; c–cannon pinion; d–claw clutch.

Wheels and pinions have spur teeth. The claw clutch and the winding pinion have face teeth — formed and angular.

In order to obtain high performance from the gear transmission it is necessary that the wheels and pinions have accurate dimensions and that the wheels have a class 8 or 9 surface-finish quality, and the pinions a class 11 to 13 finish. In order to ensure accurate center distances in plates and bridges, the holes are sized (see Chapter VI).

TOLERANCES ON GEARING ELEMENTS

Accuracy classes and tolerances for 20° pressure angle involute gearing elements of module 1 mm and above have been established by GOST 1643-46. Only departmental standards exist for involute gearing of module 0.15– 1 mm.

Tolerances used in watch industry for watch gearing correspond to the departmental specifications NPM5-246-53 (see Table 2).

The departmental specifications establish tolerances for six gearing elements. The table has been prepared so that the numerical values of the tolerances for ΔD , ΔA and δf are taken with a geometrical-progression factor of 1.41, and for Δd, Δs and δt with a factor of 1.26.

TABLE 2

Tolerances for basic watch-gearing elements, in microns

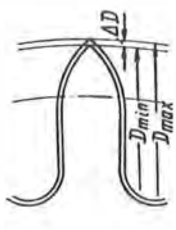
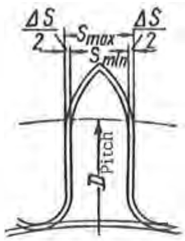
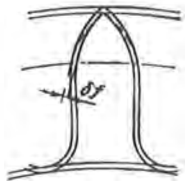
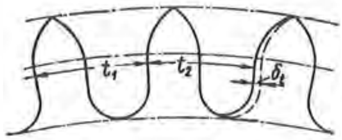
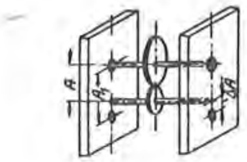
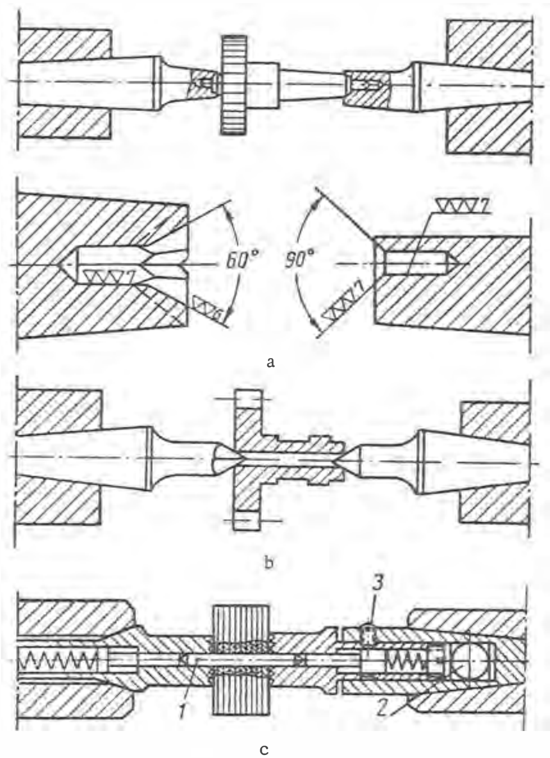
Drawing	Tolerances	Symbol	Accuracy class	Module, mm			
				from 0.05 to 0.10	from 0.10 to 0.15	from 0.15 to 0.20	from 0.20 to 0.30
	Maximum run-out, outside diameter	Δd	1	9	12	15	19
			2	12	15	19	24
			3	15	19	24	30
	Tolerance, external diameter	ΔD	1	9	12	15	19
			2	14	17	21	26
			3	20	24	28	35

TABLE 2 (cont'd)

Drawing	Tolerances	Symbol	Accuracy class	Module, mm from 0.05 to 0.10	from 0.10 to 0.15	from 0.15 to 0.20	from 0.20 to 0.30
	Tooth-thickness tolerance	Δs	1	9	12	15	19
			2	12	15	19	24
			3	15	19	24	30
	Profile tolerance	δf	1	5	6	7	8
			2	7	8	10	12
			3	10	12	14	16
	Maximum difference between adjacent circular pitches	δt	1	7	9	12	15
			2	9	12	15	19
			3	12	15	19	24
	Center distance tolerance for a gear pair	ΔA	1	±7	±9	±12	±16
			2	±10	±13	±17	±22
			3	±14	±18	±23	±30



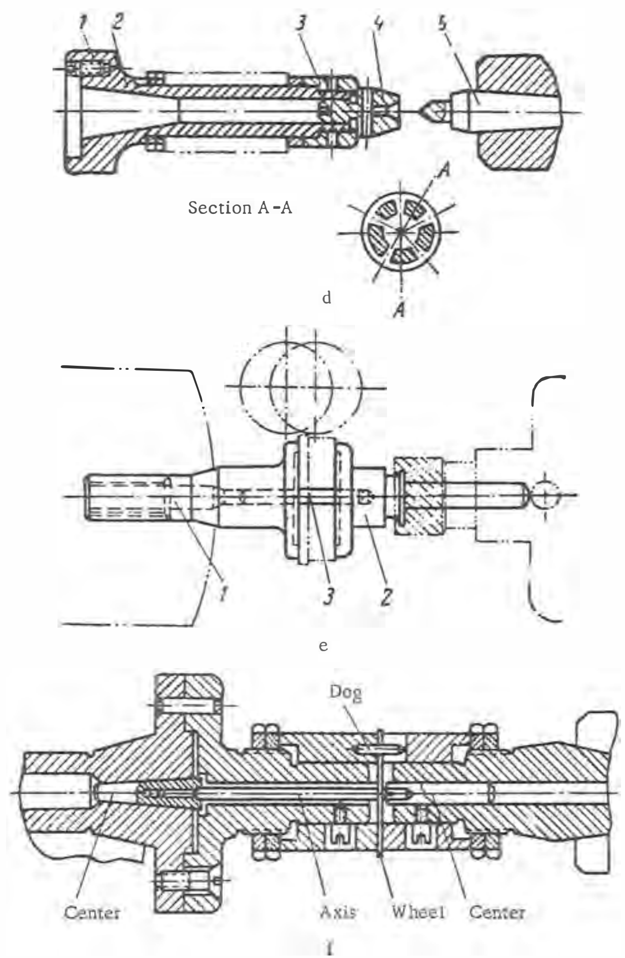


FIGURE 7. Methods of holding and positioning blanks in machines:

a–pinion blank between female centers; b–cannon-pinion blank between male centers; c–mounting and holding winding wheel blanks; d–mounting wheel blanks by sector windows; e–mounting and holding barrel-wheel blanks; f–mounting and holding wheel stacks.

Table 2 does not include tolerances for the base pitch Δt or for the displacement δh of the basic rack as do the involute gear tolerances, since the pitch circle and the base circle coincide in cycloidal and in watch gearing, and the parameter δh is replaced by the parameter ΔD in sharp-tipped teeth.

Mounting Gear Blanks in Machines

The blanks are fastened in the headstock of the machine dividing-head and the tailstock serves as a support only. The methods of holding and positioning vary, depending upon the design of the blanks.

The mounting of a pinion blank between female centers is shown in Figure 7, a. The centers have clearance holes for the journals. The blank is located on chamfers and the conical notches in the driving center grip the chamfer so that the blank rotates with the center. The tailstock center serves as a support.

The cannon-pinion blank is mounted between male centers (Figure 7, b). The driving center grips the hole chamfer, with its sharp edges forcing the blank to turn with the center. The tailstock center serves as a support.

Barrel-wheel blanks having a small-diameter central hole are set on the mandrel (1) in a stack (Figure 7, c) and are mounted between centers. Here both centers are knurled on their faces and drive the work. The tailstock center rotates with the mandrel, the ball (2) serving as a thrust bearing. The tailstock spindle retracts together with the center, being connected to it by the set screw (3) which fits into an annular groove on the center.

Wheels having sector windows in addition to the central hole are mounted on sector tongues on the mandrel (Figure 7, d). The mandrel (2) is centered by a recess on the shoulder of the headstock spindle nose. The nut (3) serves for pressing the blanks against the mandrel shoulder. The center (4) fits the mandrel hole, its female cone accommodating the tailstock center (5) The pin (1) serves as a driver for rotating the mandrel.

The mainspring barrel with a 3.2 mm diameter hole (Figure 7, e) is mounted and held on the mandrel (1) which has a shank fitting the dividing-head spindle bore and replacing the driving center. The chuck (2) is mounted in the tailstock center and the pin (3) centers the blank in the mandrel.

The mounting and positioning of wheel blanks for stack milling is shown in Figure 7, f. The method of milling in stacks is used for wheels whose run out in the stack must not exceed 0.01 mm.

MILLING TEETH USING FORMED CUTTERS

The methods used for milling the teeth of wheels and pinions in watch production are the form-milling method (division), using a profiled disk cutter, and the generation method using a hob.

The form-milling method is used for milling the teeth of ratchet wheels, segments and pinions with fewer than 12 teeth ($z \leqslant 12$). If hobbing machines are not available, wheels and pinions with more than 12 teeth can also be form-milled.

The profile of the milling cutter (Figure 8) corresponds to the profile of the tooth spaces of the wheel or pinion to be milled.

When one cut has been completed the blank is automatically indexed by the angle $360°/z$ (z = the number of teeth on the wheel or pinion to be milled), and another tooth space is milled.

Pinions are milled one at a time and thin wheels are milled in stacks of 30 to 50 pieces.

The milling is performed on specialized automatic and semiautomatic machines (models S-40, S-51, S-53, S-186, etc.).

The S-40 automatic gear-milling machine is designed for milling wheels and pinions with a maximum module of 0.5 mm for brass and 0.35 mm for steel, over a milling length of 12 mm. If the blanks are loaded manually, blanks up to 20 mm diameter can be milled. If magazine loading is used, the maximum diameter is 5 mm. The machine can operate automatically or semiautomatically.

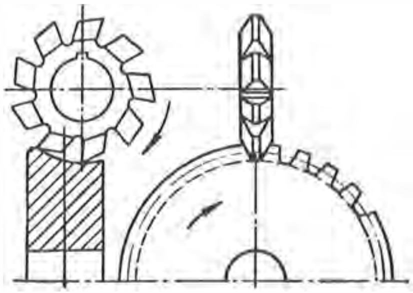


FIGURE 8. Tooth milling with a formed cutter

Power is transmitted from the electric-motor pulley (1) through a flat belt to the pulley (2) on countershaft I (Figure 10). Pulley (4) or (5) on countershaft II is driven by pulley (2), and pulley (3) drives either pulley (14) or (15) on the worm-gear shaft (9).

Pulleys (4) and (14) are keyed to their shafts while (5) and (15) are idlers. Shaft II drives the worm (18) through the three-step pulleys (7) and (13) (round belt) and the rotation is transmitted through the worm gear (18 – 19) to the main camshaft. The formed cutter spindle is driven from countershaft II by a round belt on pulley (12) and the two-step pulley (6). The belt passes over the guide idlers (10) and (11). The auxiliary camshaft is pcwered from the pulley (14) through the worm gear (9 – 17). The coolant-feed gear pump is driven from countershaft II by pulleys (8) and (16).

Starting and stopping of the shaft II is automatic. The automatic action of the machine is controlled by fixed cams mounted on the main and auxiliary camshafts (Table 3).

The machine operates as follows:

The cam A advances the table with the dividing head from left to right in a uniform motion. The form cutter mills one tooth space. The cam B then lifts the milling-cutter head in order to enable the table to return freely, without the cutter scratching the blank. The drop in the profile of cam A allows the table to be returned to the left by a spring. Cams C and D then go into action. Cam D lifts the left end of the lockpin lever and pulls it out of the index plate slot. Cam C next lifts the left end of the push lever, and the pawl goes down, rotating the ratchet wheel, and the index plate together with it, by one tooth. The ratchet wheel is fitted in the same bushing as the index plate and the relative position of the ratchet-wheel tooth and the index-plate slot is adjusted by means of special bolts during the machine setup.

The ratchet wheel and the index plate have the same number of teeth as the wheel to be milled, or a multiple thereof. Both disks are replaceable.

The lockpin enters the next slot under the action of a spring. The pawl is raised by the spring and engages the next tooth. The cam B frees the form-cutter head, which then descends to its initial position under the action of a spring. The head is held in this position by a strong spring. This terminates the machine cycle for one main-camshaft revolution. The process is repeated until the first cutter has milled all the tooth spaces. The second cutter is then engaged automatically. A dog P, fitted on the dividing-head bushing together with the index plate and the ratchet wheel, meshes with a three-tooth segment when the index plate reaches its initial position. The segment is rotated by one tooth and, through a lever train, rotates the shaft carrying cams I and J by 120°. Cam I disengages from the setting screw (22) on the cutter table, and the table is moved forward by a spring until the setting screw (21) comes into contact with cam J. When the second cutter has finished its work and the index plate has again made a full revolution, the dog P meshes with the second tooth of the segment and rotates it. The shaft carrying cams I and J again rotates 120°. The cam J then loses contact with the setting screw (21) and the cutter head moves forward until the setting screw (20) makes contact with an abutment face on the machine.

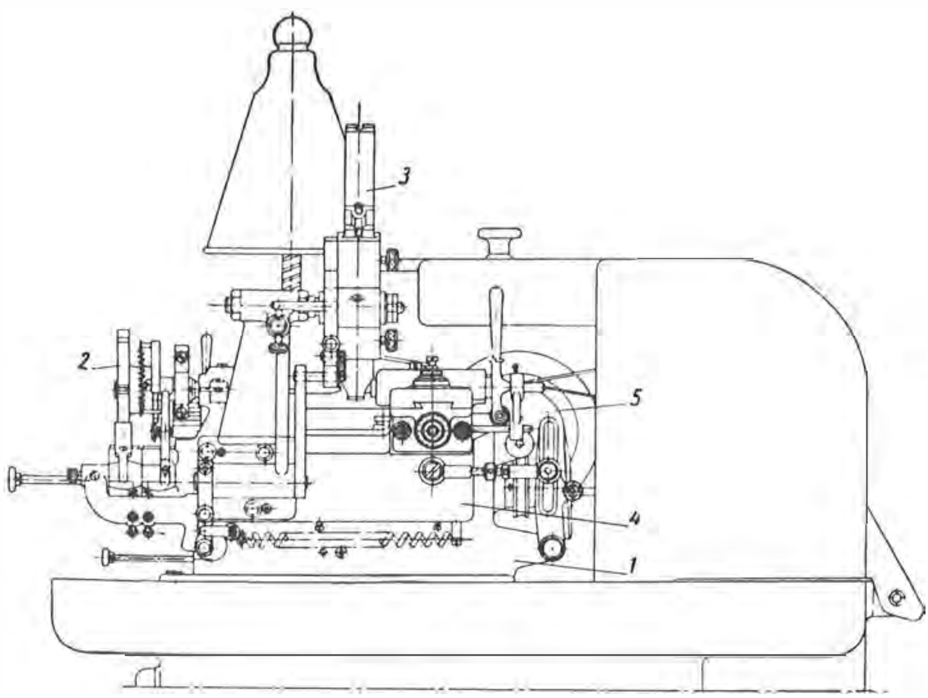


FIGURE 9. General view of the S-40 machine:

1–bed; 2–dividing head; 3–feeding device; 4–table with headstock and tailstock; 5–table-feed lever.

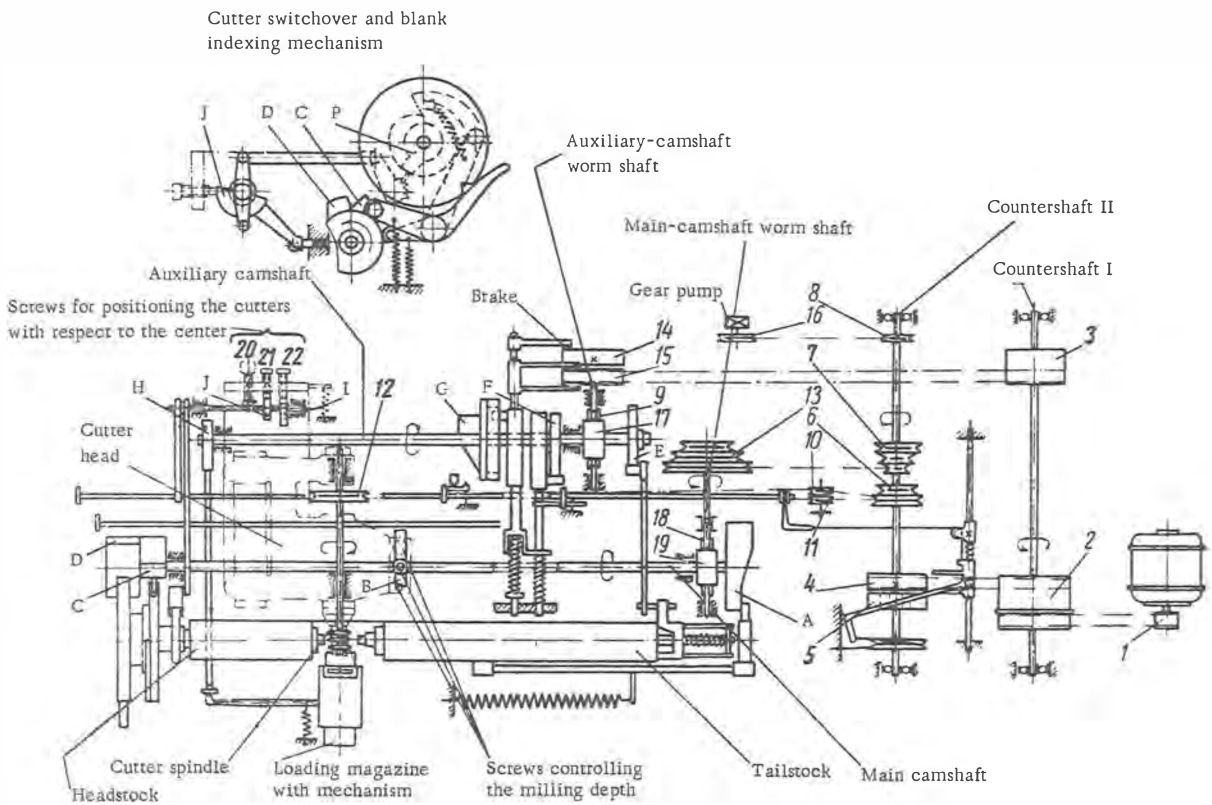


FIGURE 10. Kinematic scheme of the S-40 machine

After the third cutter has finished its work the dog meshes with the third tooth of the segment. The camshaft rotates by 120°, and the cam I brings the cutter head to its initial position. Simultaneously the segment frees the starting bar. The belt is transferred from the keyed pulley (4) to the idler (5) (on shaft II), and this stops the rotation of the main camshaft, the cutter spindle and the pump. The starting bar shifts the belt from the idler (15) to the keyed pulley (14), and with the aid of a lever and ring thus starts the auxiliary camshaft. The cam E, acting through a lever system, draws the tailstock spindle to the right and frees the blank. The cam H controls the blank feed device. To clamp the tailstock, the cam G returns the starting bar to its former position, that is, starts the main camshaft, the cutter spindle and the pump. At that moment cam F shifts the belt from pulley (14) to pulley (15), thus stopping the auxiliary camshaft. In order to ensure rapid stoppage, a brake is applied to the face of pulley (14).

TABLE 3

Cams of the S-40 automatic milling machine

Cam symbol in the kinematic scheme	Cam function	Cam type	Maximum lift, mm	Lever arm ratio
A	Worktable feed	Bell	7	0.6–1.8
B	Cutter-head lift	Flat	10.5	1:1
C	Ratchet wheel and the index-plate rotation	"	6	1:2.8
D	Index-plate lockpin release . .	"	6	1:1.25
E	Tailstock-spindle return for freeing the milled blank . .	"	9.25	1:0.8
F	Auxiliary-camshaft disconnection	"	18.5	1:1
G	Connecting (starting) the cutter spindle, main camshaft and pump	Bell	23	1:1.5
H	Feeding the blank tray from the magazine to the centers	Flat	15	1:1
I	First cutter-table set screw . .	"	9	–
J	Second cutter-table set screw	"	9	–

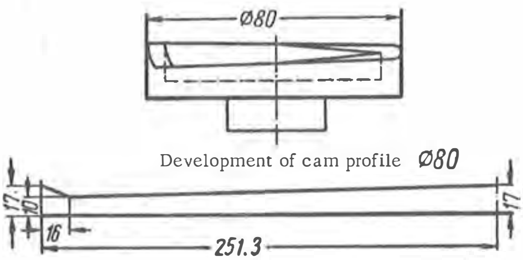


FIGURE 11. Dimensions and profile of cam A

If only one or two milling cutters are used, the switch-over takes place after one or two dividing-head revolutions, respectively. The segment meshes a corresponding number of times with the dog. The positioning of each cutter with respect to the center and milling depth is realized by means of setting screws, which are provided with dial scales with divisions of 0.01 mm. The main camshaft has three speeds: 9, 19.2 and 30 rpm. The cam A being fixed, the table-feed rates are changed by changing the main-camshaft speed and the ratio of the lever arms (5) (between 0.6 and 1.8). The range of feeds is 64.8 to 648 mm/min.

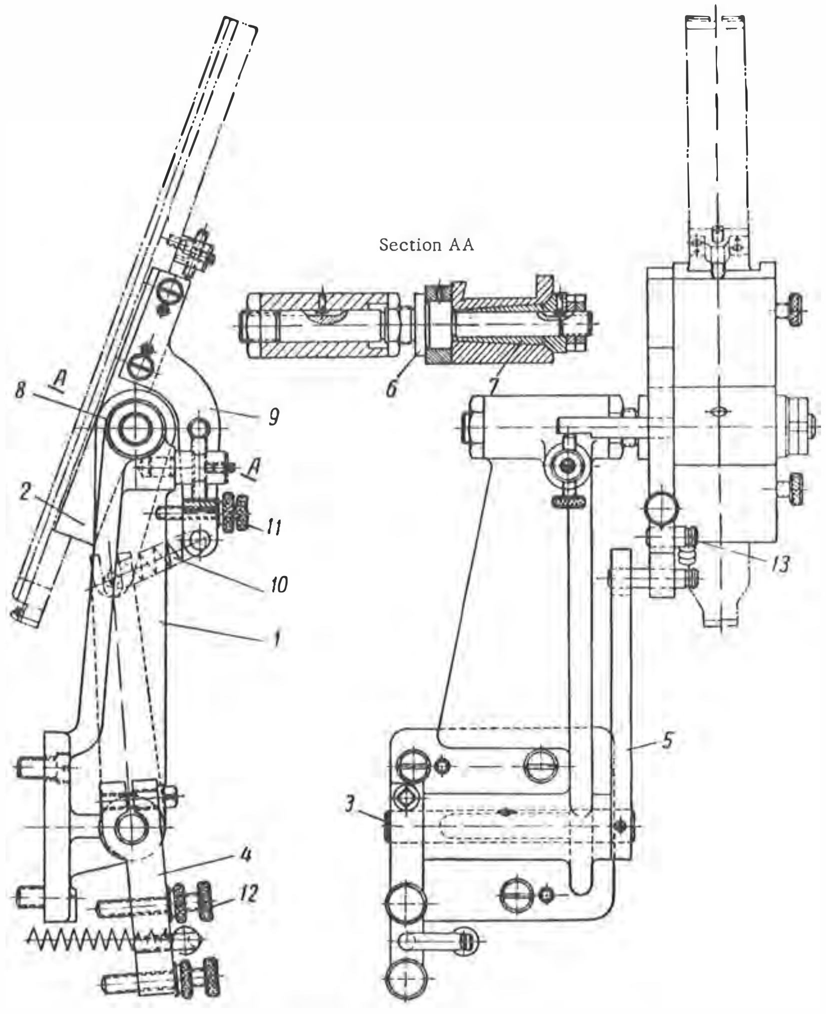


FIGURE 12. Loading device for the S-40 machine

According to the cam cycle diagrams, 93.5% of the movements are machining movements, and 6.5% are idle movements (Figure 11). The idle movement of the return of the cutter to its initial position and the simultaneous indexing motion of the dividing head are the main shortcoming of the form-milling machines.

The S-40 machine is equipped with a special device for automatically feeding blanks from the magazine into the machining zone (Figure 12).

The loading mechanism consists of the bracket (1), the body (2), a lever system, and setting screws.

The bracket has two bushings. The shaft (3) rotates in the lower bushing, and the levers (4) and (5) are mounted on its projecting ends.

The upper bushing carries the axis (6), on whose projection the body (2) pivots. The conical bushing (7) is used for adjusting the fit of the body on the axis.

The lever (8) rotates freely on the axis (6) while the lever (9) is fixed to the body. Levers (8) and (9) are connected by the spring (10) and the distance between their free ends is fixed during the setup by the screw (11).

The mechanism is actuated by the camshaft cam through a plunger. The plunger acts on the lower screw (12) on lever (4) which, by rotating the shaft (3), rotates the lever (5) fastened to the other end of the shaft. The lever (5), through its forked end, the pin (13) and the spring (10), rotates the lever (9) which is rigidly fixed to the body carrying the magazine. The necessary magazine slope is thereby obtained.

Technical data, S-40 machine

Spindle speed, rpm	1000 or 2000
Main-camshaft speeds, rpm	9; 19.2; 30
Maximum blank diameter when working with the loading device, mm	5
Maximum blank diameter with manual loading, mm	20
Maximum milling length, mm	12
Maximum gear module, mm:	
a) brass	0.5
b) steel	0.35
Minimum number of teeth	6
Milling speed, m/min	From 40 to 100
Feed, mm/min	From 64.8 to 648
Index-plate error, angular pitch	0°02'
Cutter spindle radial run-out, mm	0.003— 0.008
Dividing-head spindle radial run-out, mm	0.005— 0.01
Nonalignment of the axes of the headstock and tailstock spindles on a length of 50 mm, mm	Up to 0.015
Misalignment of the table guides, on a length of 50 mm, mm	Up to 0.01

The S-53 machine is used for milling teeth with a maximum module of 1.5 mm for brass and 1 mm for steel. The maximum-diameter wheel or pinion which can be milled on this machine is 80 mm. The milling depth is 40 mm and the number of teeth cut can be between 6 and 100.

The machine operates semiautomatically with blank loading and the starting of the machine being executed manually.

The principles of operation of the S-53 machine are the same as those of the S-40 machine, when it is operated semiautomatically.

Disk cutters. Disk cutters are used in the form-milling method. In watch production a different cutter is designed for each wheel or pinion, depending upon its module, profile and number of teeth.

Designing proceeds as follows: the profile of the cutter tooth is drawn as the nominal profile of the tooth space of the wheel or pinion, usually to a scale of 50:1, 100:1 or 200:1 (Figure 13).

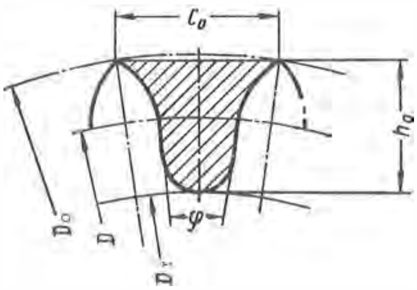


FIGURE 13. Tooth profile of a disk cutter

The values of C_0 and h_0 are calculated from the formulas:

$$C_0 = D_0 \cdot \sin\frac{180^\circ}{z},$$

$$h_0 = \frac{D_0 \cos\frac{180^\circ}{z} - D_r}{2},$$

where C_0 = the circular pitch of the wheel or pinion;
h_0 = the total tooth depth;
z = the number of teeth;
D_0 = the outside diameter;
D = the pitch diameter;
D_r = the root diameter.

The cutter dimensions are selected from Table 4, which gives the design dimensions of formed cutters as functions of C_0 and h_0.

The allowable run-out is 0.02 mm on the outside diameter, and 0.01 mm on the face.

The tooth profile of formed cutters is preserved during regrindings, as they are sharpened by grinding on the radial tooth faces. The teeth are form-relieved according to a logarithmic spiral or a similar curve.

Form-relieving creates cutting edges on both the sides and the tip of the tooth.

The following mathematical relationship exists between the lateral form-relief angles and the back angle:

$$\tan\gamma = \tan\alpha \cdot \sin\frac{\varphi}{2}\,^{*}, \qquad (1)$$

---

* Sokolov, M. A. Instrumental'noe delo (Tooling). - Gosmashizdat. 1933.

where γ = the side form-relief angle;

α = the tip form-relief angle (back angle);

φ = the angle between the tooth space hypocycloids (see Figure 13).

The milling conditions being different for wheels and for pinions, the angle α, and accordingly the angle γ, must be established as a function of the value of the angle φ.

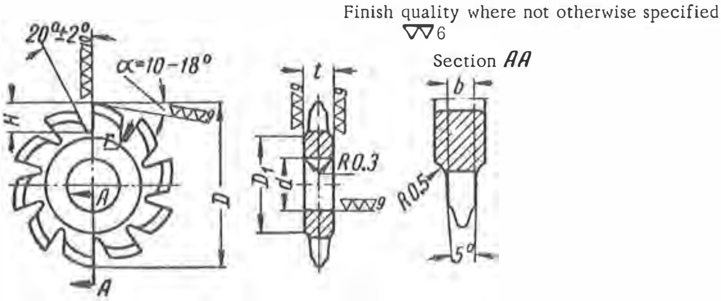
We shall illustrate this by a practical example:

for a wheel with z = 60, φ = 3°

for a pinion with z = 6, φ = 40° (see Appendix 2).

TABLE 4

Disk cutters



h_0	C_0	D		D_1		d		H		t		r
		nominal	tolerance	nominal	tolerance	nominal	tolerance	nominal	tolerance	nominal	tolerance	
Up to 0.6	Up to 0.55	8	−0.36	6	−0.48	3.5	+0.013	1	+0.12	2	−0.06	0.2
0.6	0.75	8	−0.36	5.5	−0.48	3.5	+0.013	1.2	+0.12	2	−0.06	
0.6	0.75	12	−0.43	9	−0.58	5	+0.013	1.4	+0.12	2	−0.06	0.3
0.6–0.8	0.75	12	−0.43	8.5	−0.58	5	+0.013	1.6	+0.12	2	−0.06	
0.6–0.8	1.0	12	−0.43	8.5	−0.58	5	+0.013	1.6	+0.12	2	−0.06	
0.8–1.0	1.2	12	−0.43	8	−0.58	3.5	+0.013	1.9	+0.12	2	−0.06	0.4
1.0–1.2	1.4	12	−0.43	7	−0.58	3.5	+0.013	2.4	+0.12	2	−0.06	
Up to 0.6	Up to 0.75	16	−0.43	12.5	−0.7	5	+0.013	1.4	+0.12	2.5	−0.06	0.4
0.6–0.8	1.0	16	−0.43	12.5	−0.7	5	+0.013	1.6	+0.12	2.5	−0.06	
0.8–1.2	1.2	16	−0.43	11	−0.7	5	+0.013	2.2	+0.12	2.5	−0.06	
1.2–1.4	1.2	16	−0.43	11	−0.7	5	+0.013	2.4	+0.12	2.5	−0.06	
0.8–1.0	1.2	20	−0.52	15	−0.7	8	+0.016	2.2	+0.12	2.5	−0.06	0.6
1.0–1.25	1.5	20	−0.52	15	−0.7	8	+0.016	2.5	+0.12	2.5	−0.06	
1.0–1.7	2.5	24	−0.52	16	−0.7	8	+0.016	5	+0.16	3	−0.08	1
1.7–2.5	2.7	24	−0.52	14	−0.7	8	+0.016	6	+0.16	3	−0.08	
1.25–1.75	2.5	30	−0.52	20	−0.8	10	+0.016	5	+0.16	4	−0.08	

Taking α = 10°, we obtain by substituting into (1) for the wheel:

$$\tan\gamma = \tan 10° \sin\frac{3°}{2} = 0.004615,$$

$$\gamma_w = 15';$$

for the pinion:

$$\tan\gamma = \tan 10° \sin 20° = 0.06,$$

$$\gamma_p = 3°30'.$$

We see that for α = 10° the milling conditions for the wheel are very unfavorable. If such a formed cutter were used to mill brass wheels, its side edge would be rapidly blunted and brass would accumulate on it, a fact frequently attributed erroneously to the insufficient hardness of the cutter.

No such brass accumulation will be observed on the pinion cutter. In order to improve the cutting conditions for wheels, the angle α = 18° is selected. This will give us γ = 0°30'.

The angle α = 18° is optimal for cutters with 16 and more teeth. With a further increase in the angle α the process of cutter form-relief becomes difficult and the manufacture of the form-relieving tool becomes complicated.

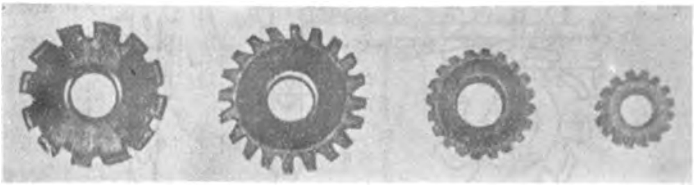


FIGURE 14. Watch-gearing profile formed cutters

Since brass wheels are cut in one pass, the cutter must have the maximum possible number of teeth in order to obtain the required surface-finish quality.

Cutters designed for machining pinions with $z \leqslant 16$ can be made with α = 10°. In all other cases the value of α must be established within the range 10 – 18°.

Figure 14 is a photograph of formed cutters of 12, 16 and 20 mm diameter, with 12, 16 and 20 teeth.

CUTTING CONDITIONS IN FORM-MILLING

Brass wheels are milled on the S-40 and S-53 machines in one pass. Pinions made of high-carbon steel are usually milled in two passes and, in particular cases, in three passes. When three passes are required, three cutters are mounted in the mandrel (Figure 15). The first cutter, a slotting cutter, is called the stocking cutter. The second cutter is a gear cutter used for rough milling, while the third tool is a gear cutter for finish milling.

When working with two cutters only, the two gear cutters are used. Two-pass milling is the best variant: the machine production rate is considerably higher than when working with three cutters, while the surface quality is the same.

The service life of the finishing cutter is the same regardless whether two or three passes are made, since the slotting cutter facilitates only the work of the roughing cutter. The service life of slotting cutters is lower than that of formed gear cutters. The service life of the finishing cutter (between regrindings), when milling wheels and pinions made of U10A steel, is 7 to 8 hours machining time.

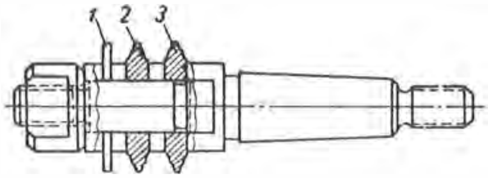


FIGURE 15. Mandrel with cutters:

1–slotting cutter; 2–gear cutter (roughing); 3–gear cutter (finishing).

The milling conditions – the feed and speed – are selected as a function of the mechanical properties of the material, the blank dimensions and the cutter material.

If we take the cutting speed of a cutter made of an alloy tool steel such as KhVG, Kh, etc. as being unity, then the cutting speed for cutters made of high-speed steels such as R18 will be 1.5, and that of cutters made of carbon steels such as U12A will be 0.9.

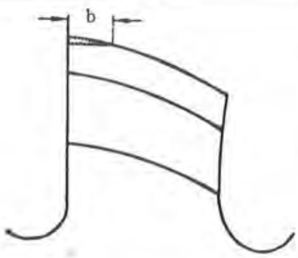
It is recommended that alloy-steel cutters be used for milling brass wheels and pinions and that high-speed-steel cutters* be used for milling wheels and pinions made from U10A or U7AV steel.

The cutting edges of the cutter teeth become worn during the milling process and wear is most severe at the tooth point, the specific load there being much higher than along the lateral surfaces.

The criterium for tooth blunting is the width of the wear land b, given in Table 5.

TABLE 5

Acceptable value of cutter-tooth blunting



Cutter type	Material machined	Wear b, mm
Hob	Steel Brass	0.15—0.25 0.07—0.10
Disk	Steel	0.1—0.2

Feeds. The feed rate is established, as already mentioned, as a function of the mechanical properties of the material, the module and the number of

* The method of manufacturing cutters from the VK6 hard alloy has now been mastered. The service life of such a cutter is several times longer than that of earlier cutters.

teeth on the wheel or pinion. Higher feeds are used in milling brass than in milling steel. With an increase in the number of teeth and in the module the size of the blank increases together with its strength and rigidity, and therefore higher feeds can be used.

In addition, for a given module the tooth space decreases in size with an increase in the number of teeth, and the decreased volume of metal removed, permits the use of higher feed rates.

The following formula is used to determine the feed:

$$s_z = C_s M^a \cdot z^b \text{ mm/tooth*},$$

where s_z = feed per cutter tooth, mm;
C_s = a machinability factor;
z = number of teeth on the wheel or pinion being milled;
M = module of the wheel or pinion teeth.

The values of the factor C_s and the exponents a and b are given in Table 6.

TABLE 6

Values of the factor C_s and the exponents a and b

Cutting tool	Material machined	Factor and exponents		
		C_s	a	b
Hob cutters	Steel	0.158	0.54	0.265
	Brass	0.275	0.54	0.32
Disk cutters	Steel $z \leqslant 12$	0.008	0.72	1.5
	$z > 12$	0.014	1	0.55
	Brass $z \leqslant 12$	0.0017	0.72	1.5
	$z > 12$	0.03	1	0.55

The cutting speed is established as a function of the mechanical properties of the metal, the gear module and the feed.

The formula used for the determination of the cutting speed is:

$$v = \frac{C_v M^x}{s_z^y} \text{ m/min.}$$

The values of the factor C_v and of the exponents x and y are given in Table 7.

As a time-saving device, the recommended cutting conditions of the milling of wheels and pinions by disk cutters are given in Tables 8, 9, and 10.

The milling time T_m for a wheel or a pinion is determined from the formula

$$T_m = \frac{L \cdot z_g}{n \cdot s_z \cdot k \cdot z_f}, \tag{2}$$

where z_g = number of teeth on the wheel;
z_f = number of teeth on the form cutter;
k = number of parts machined simultaneously;
s_z = feed per tooth, mm;

----

* Standards of the "Orgmashpribor" Institute for gear manufacture. 1954.

n = cutter speed, rpm;
$L = l + l_1 + l_2$, = total travel, where l is the length of the wheel or pinion milled (or of several wheels), l_1 is the approach distance (see table in Appendix 3), and l_2 is the cutter overtravel (1 – 1.5 mm).

The value of l_1 can be determined from the formula

$$l_1 = \sqrt{h_0 (d - h_0)}, \tag{3}$$

where h_0 is the depth of cut and d is the cutter diameter.

TABLE 7

Values of the factor C_v and the exponents x and y

Cutting tool	Material machined	Factor and exponents		
		C_v	x	y
Hob cutters	U7AV steel	13.4	0.42	0.43
	U10A steel	12.2	0.42	0.42
	Brass	141.5	0	0.16
Disk cutters	U7A V steel M = 0.1–0.2	385	1.8	0.38
	$M > 0.2$	47.6	0.5	0.38
	U10A steel M = 0.1–0.2	350	1.8	0.38
	$M > 0.2$	43.2	0.5	0.38

TABLE 8

Feed, s_z, in mm/tooth for milling teeth on wheels and pinions made from U7AV, or U10A steel using disk cutters

Number of teeth on the wheel or pinion	Module, mm							
	0.1	0.12	0.14	0.16	0.18	0.20	0.25	0.30
8	0.0034	0.0039	0.0043	0.0048	0.0052	0.0056	0.0066	0.0075
10	0.0048	0.0055	0.0061	0.0068	0.0073	0.008	0.0094	0.011
15	0.0062	0.0074	0.0087	0.010	0.011	0.012	0.015	0.019
20	0.0073	0.0088	0.010	0.012	0.013	0.015	0.018	0.022
30	0.0091	0.011	0.013	0.014	0.016	0.018	0.023	0.027
40	0.011	0.013	0.015	0.017	0.019	0.021	0.026	0.032
50	0.012	0.014	0.017	0.019	0.022	0.024	0.030	0.036
60	0.013	0.016	0.018	0.021	0.024	0.026	0.033	0.040
70	0.014	0.017	0.020	0.023	0.026	0.029	0.036	0.043
80	0.016	0.019	0.022	0.026	0.029	0.032	0.040	0.048

TABLE 9

Cutting speed, v, in m/min, for milling teeth on wheels and pinions made from U7A V steel using disk cutters

Feed, s_z mm/tooth	Module, mm							
	0.1	0.12	0.14	0.16	0.18	0.20	0.25	0.30
0,002	59	91	119	–	–	—	—	—
0,003	50,3	77,3	101	125	159	—	–	—
0,004	45.1	69.3	91	115	143	173	—	—
0.005	41.4	63.5	83.7	106	131	160	177	195
0,006	38.7	58	76	96	119	145	162	178
0,008	35	53.8	70.5	89	110	134	150	164
0,010	31,9	49.2	64,4	81.5	100	122	136	150
0.015	27.2	42	55	70	86,6	106	118	129
0,020	24.5	36,6	49.7	63.5	78	94.7	105	116
0,025	22.5	34.7	45.6	57.7	71.5	86.5	96.6	106
0.030	21.0	32.3	42.3	53.8	66.5	81	90.2	99
0,040	—	—	—	48.3	60	72.5	80.8	89
0,050	—	—	—	—	—	66.7	74.2	81.4

TABLE 10

Cutting speed, v, in m/min, for milling teeth on wheels and pinions made from U10A steel using disk cutters

Feed, s_z mm/tooth	Module, mm							
	0.1	0.12	0.14	0.16	0.18	0.20	0.25	0.30
0.002	53.6	82.5	108	—	—	—	—	—
0.003	45.8	70.3	92	117	145	—	—	—
0.004	41,0	63.0	82.5	105	130	157	—	—
0.005	37.6	57.7	76	96	119	145	161	177
0.006	35.2	52,7	69	87.5	1C8	132	147	162
0.008	31.7	48.7	64	81	100	122	135	149
0,010	29	44.5	58.4	74	92	111	124	136
0.015	24.8	38.2	50	63.5	78.7	96	107	117
0.020	22.3	34.3	45	57.1	71	86	95.5	105
0,025	20.5	31.5	41.2	52.4	65	78.5	87.6	96.5
0,030	19.1	29.4	38,5	48.8	60.5	73.4	82	90
0.040	—	—	—	43.8	54.5	66	73.4	80.8
0,050	-	—	—	—	—	60.6	67.5	74

The idle-cycle time and the machine-setup time must be added to the milling time calculated according to (2). The idle-cycle time is determined from the technical data of the machine. For the S-40 machine the idle movements take roughly 7% of T_m.

Having calculated the machine-cycle time $T_{mach} = T_m + T_i$ for machining one part, it is compared with the technical data of the machine, and the camshaft speed closest to that which would give one camshaft rotation during T_{mach} is selected. The calculated cutting speed is also compared with the machine capabilities and the closest available form-cutter spindle speed is selected. The method of calculation of the cutting conditions and the machine production rate will be illustrated in the following example.

It is required to mill the teeth of a third-wheel pinion of module 0.103 mm, $z = 8$. The length of cut is $l = 0.80$ mm, the material U7AV steel.

The data necessary for the calculation are first written down.

The feed per tooth of the form cutter is $s_z = 0.0034$ mm (Table 8).

The cutting speed is $v = 50.3$ m/min (Table 9).

The form-cutter dimensions are taken from Table 4:

diameter 8 mm, 16 cutter teeth.

The cutter-spindle speed chosen is $n = 2000$ rpm.

The length of cut is, from the drawing, $l = 0.8$ mm.

The cutter approach is $l_1 = 1.5$ mm (Appendix 3).

The overtravel is selected as $l_2 = 1.2$ mm.

The total travel is therefore $L = 3.5$ mm.

The time required for milling the pinion in one pass is according to (2)

$$T_m = \frac{L \cdot z_g}{n \cdot s_z \cdot k \cdot z_f} = \frac{3.5 \cdot 8}{2000 \cdot 0.0034 \cdot 1.16} = 0.25 \text{ min.}$$

The idle movements taking, according to the machine data, 7% of the milling time, we have

$$T_i = \frac{0.25 \cdot 7}{100 - 7} = 0.02 \text{ min.}$$

The machine-cycle time required for machining the pinion in one pass will therefore be

$$T_{mach} = T_m + T_i = 0.25 + 0.02 = 0.27 \text{ min.}$$

If two passes are to be made, we must add the time taken by the form-cutter shifting which requires one camshaft revolution. At $n_{aux} = 20$ rpm this takes $1/20 = 0.05$ min.

The piece time, T_p, for one cycle of the S-40 machine will therefore be

$$T_p = T_m + T_i + T_{aux} = 0.25 + 0.02 + 0.05 = 0.32 \text{ min.}$$

For two passes, this time is doubled, and is 0.64 min.

The calculated production rate of the machine will be $A = \frac{480}{0.64} = 750$ pieces per working shift.

The data obtained are then compared with the machine data.

The camshaft speeds available are $n = 9$, 19.2 or 30 rpm; the time per camshaft revolution will accordingly be: 0.11, 0.052, or 0.033 min. The calculated time T_{mach} required for milling one tooth is $0.27/8 = 0.034$ min.

According to the specifications of the machine, the value closest to this is 0.033 min, corresponding to $n = 30$ rpm.

The actual machine production rate will therefore be $A = \frac{480}{2(0.0033 \cdot 8 + 0.05)} = 764$ pieces per shift.

The pinion blanks obtained from Swiss-type automatic screw machines, and the wheel blanks obtained from high-quality stamping dies, have minimum milling allowances. The diameter allowances for steel pinions are set at 0.05 to 0.15 mm, for brass wheels at 0.07 to 0.20 mm, and for steel wheels at 0.15 to 0.30 mm.

The surface-finish quality of form-milled brass and steel pinions and wheels of 0.05 to 0.3 mm module is class 8 or 9, and that of wheels of 0.3 to 0.5 mm module is class 7 or 8.

MILLING FACE (CONTRATE) TEETH

The milling of face teeth on the crown wheels, winding pinions and claw clutches of watch mechanisms, and on other similar parts, is performed on S-51 and S-186 copy-milling and indexing machines.

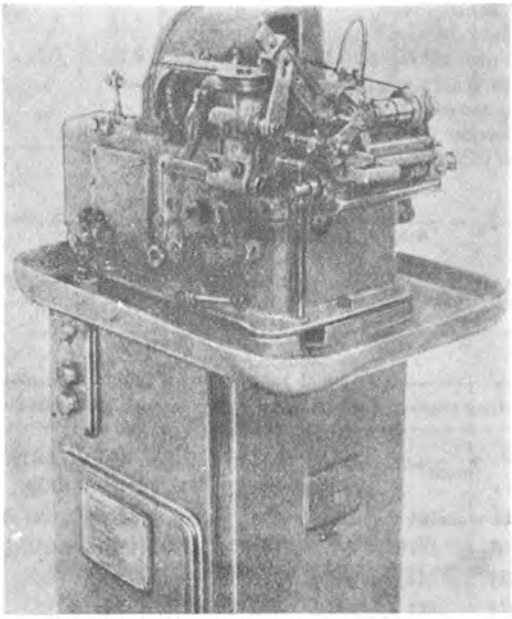


FIGURE 16. S-186-type face-gear milling machine

The S-186 is the most versatile model (Figure 16).

The S-51 machine is semiautomatic; 8 mm is the maximum wheel diameter and 0.3 mm is the maximum module which can be milled on this machine.

The S-186 machine is semiautomatic but can also operate automatically with one disk cutter. Milling can be carried out in two passes. The semiautomatic machine has horizontal and vertical feeds for infeed face milling and cross-feed milling, respectively.

Infeed milling is used when cutting teeth of negligible length and open profile.

Cross-feed milling is used when cutting teeth of considerable length or teeth with an undercut profile (ratchet teeth). In the latter case the headstock with the form cutter swivels up to 5°.

Cross-feed milling gives a better surface-finish quality and a more accurate profile than does infeed milling. The machine operates automatically when milling parts of a diameter smaller than 9 mm, and semiautomatically when milling larger parts of diameters up to 25 mm. The manual loading of blanks is performed by a special loading carriage which feeds them to the collet. The ejection of the parts is performed automatically.

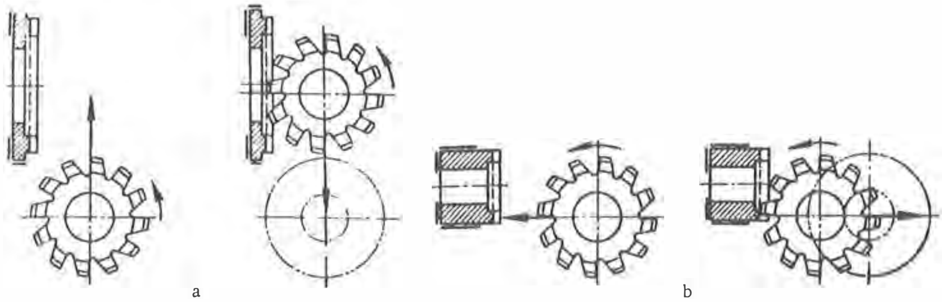


FIGURE 17. Position of the form cutter in milling:
a–cross-feed milling; b–infeed milling.

The kinematic diagram of the S-186 machine is given in Figure 18. The machine is driven by an electric motor placed inside the machine base.

The cutter-spindle pulley (5) is powered by a round belt from the first step of the electric-motor pulley (1), through the countershaft pulleys (3) and (4).

The speed of rotation can be increased by changing pulley (4).

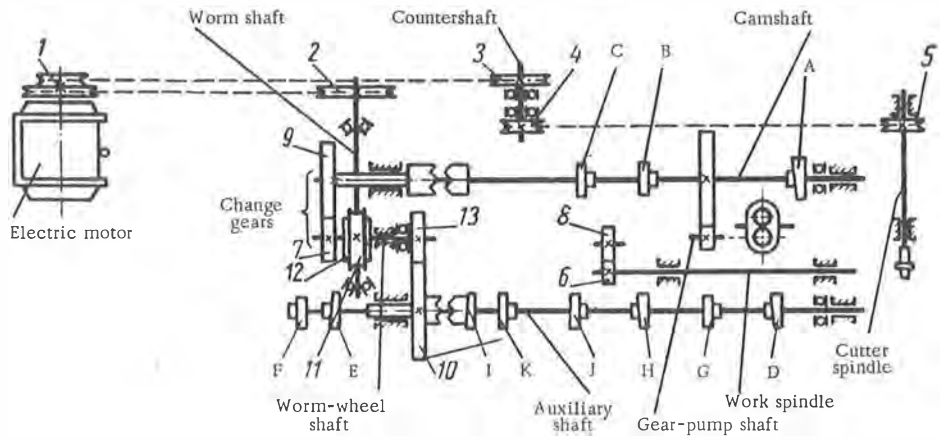


FIGURE 18. Kinematic diagram of the S-186 machine

The worm-shaft pulley (2) is powered from the second step of the electric-motor (pulley (1). The worm and wheel (11 – 12) transmit power to the worm-wheel shaft.

The worm-wheel shaft powers:

a) the camshaft through the change gears (7) and (9) and claw clutches;

b) the auxiliary shaft through the fixed gears (13) and (10) and claw clutches.

The camshaft and the auxiliary shaft operate successively. The camshaft has six speeds while the auxiliary shaft rotates at a fixed speed.

The camshaft powers the gear pump through a gear set, and is started and stopped automatically by means of claw clutches controlled by the cam J on the auxiliary shaft. The auxiliary shaft is started by the catch on the dividing-head gear (8), and stopped by cam I, which is integral with the one-turn claw clutch on the auxiliary shaft.

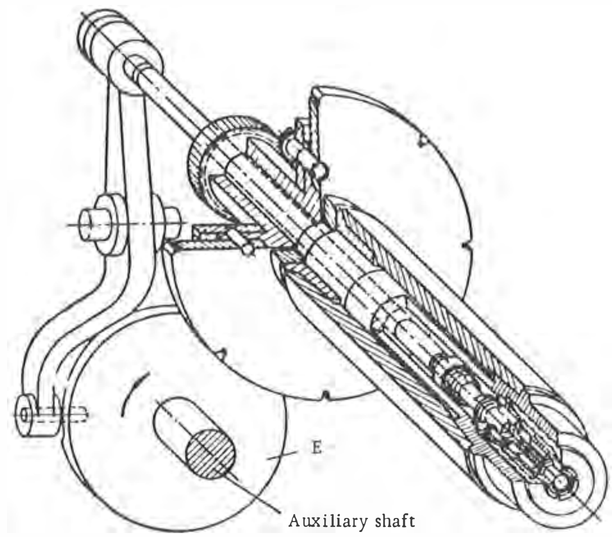


FIGURE 19. Work spindle

The fixed cams A, B, and C, which control the working processes of the machine are mounted on the camshaft.

Cam A, a bell cam, controls the cutter feed in the horizontal direction for infeed milling and in the vertical direction for cross-feed milling.

Cam B, a flat cam, locks the index plate in position.

Cam C, also a flat cam, indcxes the index plate.

One tooth is milled per camshaft revolution, and the whole gear wheel is milled during one rotation of the index plate. When the milling is done in two stages (roughing and finish) the index plate executes a second rotation, and the milling cycle is repeated.

When the milling has been completed, the camshaft is stopped, and the auxiliary shaft started. The auxiliary shaft mounts the cams D, E, F, G, H, I, J and K which control the auxiliary machine functions.

Cam D, a bell cam, returns the cutter spindle to neutral position (Figure 17).

Cam E, a bell cam, opens the collet, this being followed by ejection of the gear (Figure 19).

Cam F, a flat cam, stops the machine in semiautomatic operation and is not active in automatic operation.

Cam G, a flat cam, controls the feeding mechanism in automatic operation.

Cam H, a bell cam, feeds the blank into the collet from the loading station.

Cam I, a bell cam, controls the disengagement of the auxiliary-shaft clutch. This cam is integral with the one-turn claw clutch.

Cam J, a bell cam, controls the engagement and disengagement of the camshaft clutch.

Cam K, a flat cam, locks the auxiliary shaft in a definite position.

The machine operates as follows: the cam A, through a lever system, moves the cutter slide in the horizontal plane. The cutter feed is spring-powered and controlled by a drop on the cam (see cycle diagram in Figure 20). The retraction of the cutter from the work is cam-actuated (rise curve).

The same cam A, through a lever system, can move the cutter head also in the vertical plane, the cutter slide being lowered by spring action.

Cam A can control either cross-feed or infeed milling, but not both simultaneously.

The cutter is lowered in order to permit the indexing of the blank to the next tooth. Cam B frees the index plate from the lockpin when the milling of one tooth is ended and the retraction of the cutter has been accomplished. Cam C rotates the ratchet wheel by one tooth (through a lever system), the lockpin enters the next slot on the index plate under the influence of a spring, and the milling cycle is repeated.

When the wheel has been completely milled the index-plate gear (6) (z = 30) (Figure 18) has made a full revolution.

The gear (8) (z = 60) meshed with gear (6) has completed only half a revolution and if the milling of the wheel is to be performed in one pass, the catch on gear (8) has two pins located diametrically opposite one another.

The catch disconnects the lever from cam I, which is a part of the one-turn clutch on the auxiliary shaft. The clutch is moved rapidly to the left by springs located inside the body, and meshes with the claw clutch on gear (10). The auxiliary shaft begins to rotate. If the milling is to be carried out in two passes, the catch on gear (8) has only one pin, and the auxiliary shaft is started after a complete revolution of gear (8).

Cam D, through a lever system, lowers the cutter spindle to neutral position.

Cam E, through the lever P, depresses the plunger passing inside the working spindle (see Figure 19). The collet is opened by springs, and the part is ejected by the plunger.

Cams G and H control the feed of the blank from the magazine to the feeding carriage, and from there to the collet. In the most recent model the blanks are fed directly from the magazine into the collet.

A spring-loaded lever with its left arm in the slot in cam I is caused by the rise curve to draw the claw clutch to the right, thus disengaging the clutch and stopping the auxiliary camshaft.

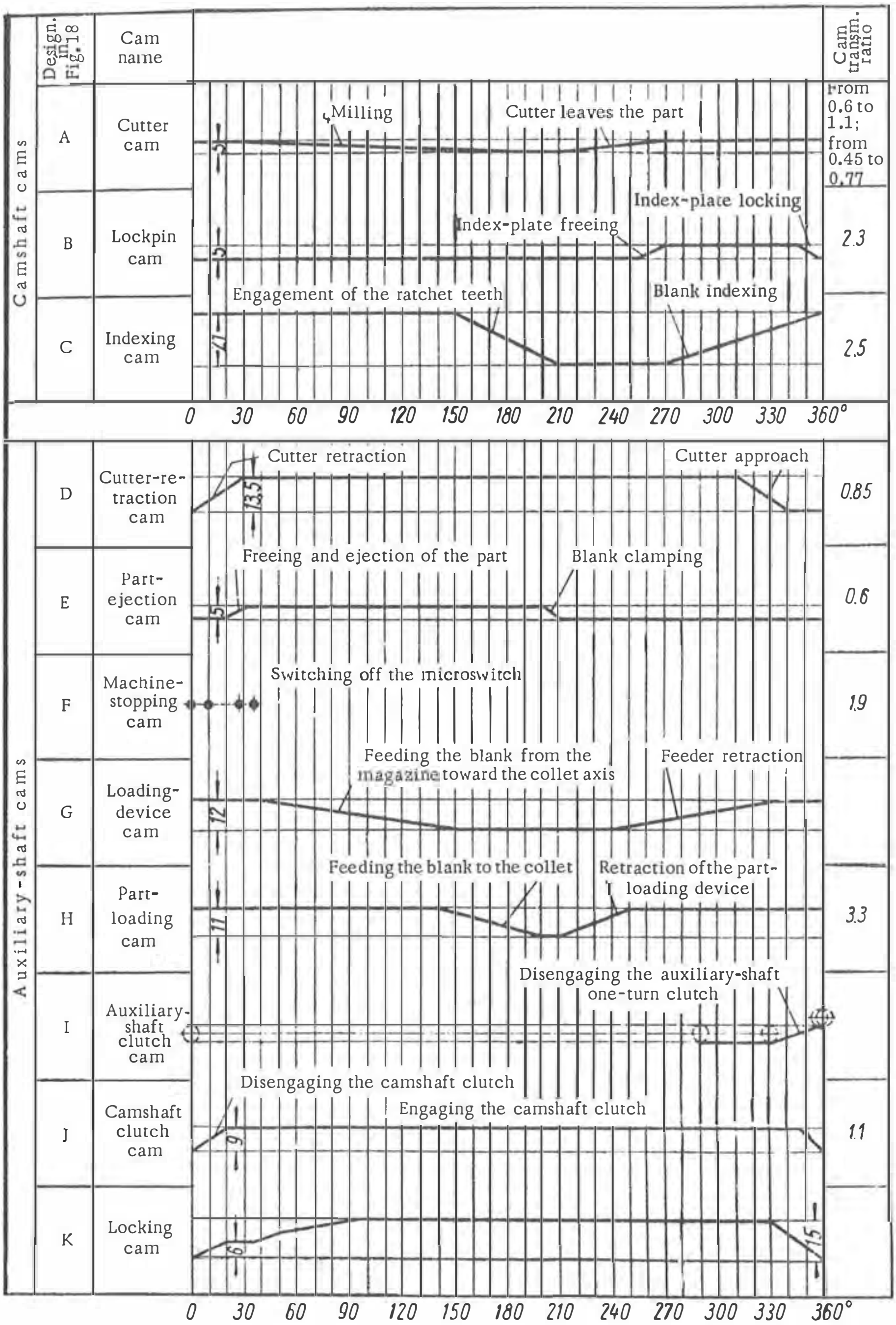


FIGURE 20. Work cycle of the S-186 machine

TABLE 11

Feeds for milling face teeth (module and oblique) in gears and clutches

Tooth depth, mm	0.2	0.25	0.3	0.4	0.5	0.6	0.8	1.0
Feed per cutter tooth, mm	0.01	0.009	0.008	0.007	0.006	0.0055	0.0045	0.004

TABLE 12

Cutting speeds for milling face teeth (module and oblique) in gears and clutches

Tool material	Material machined	Cutter diameter, mm	Feed per cutter tooth, mm							
			0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.012
R9 and R18 high-speed steels	U7AV	8	97.5	81.6	68.8	60.2	53.7	48.7	43.5	37.4
		10	107	90	76	66.5	59.5	54.1	48.2	41.2
		12	116	97.5	82.5	72	64.4	58.5	52	44.5
		16	134	112	94.5	82.5	74	67	59.4	51
		20	147	123	104	91.4	81.3	74	66	56.5
	U10A	8	87.7	73.4	62	54.2	48.2	43.7	39.2	33.6
		10	97	81	68.4	59.8	53.5	48.7	43.4	37
		12	104	87.8	74.2	64.7	58	52.6	46.7	40
		16	120	100	85	74.2	56.5	60.3	53.4	45.8
		20	132	111	94	82.3	73.4	66.5	59.5	50.8
Kh, KhVG, 9KhS alloy steels	U7AV	8	71.5	60	50.5	44.2	39.4	35.8	32	27.4
		10	78.5	66.1	55.8	48.7	43.6	39.7	35.3	30.2
		12	85.1	72	60.6	53	47.3	43	38.2	32.7
		16	98.5	82.2	66.6	60.6	54.4	49.2	43.6	37.5
		20	108	90.5	76.5	67.2	60	54.4	48.5	41.5
Kh, KhVG, 9KhS alloy steels	U10A	8	64.8	54.3	45.8	40.1	35.8	32.5	29.0	24.9
		10	71.6	60.0	50.7	44.4	39.6	36.1	32.1	27.4
		12	77.5	64.9	55	48	42.9	39	34.7	29.7
		16	89	74.5	63	55	49.2	44.6	39.8	34.0
		20	98	82.2	69.5	60.8	54.2	49.4	44.0	37.6
U12A carbon steel	U7AV	8	64.8	54.4	45.8	40.1	35.8	32.5	29.0	24.0
		10	71.6	60.0	50.7	44.4	39.6	36.1	32.1	27.4
		12	77.5	64.9	55	48	42.9	39	37.4	29.7
		16	89	74.5	63	55	49.2	44.6	39.8	34.0
		20	98	82.2	69.5	60.8	54.2	49.4	44.0	37.6
U12A carbon steel	U10A	8	59.0	49.5	41.7	36.5	32.6	29.6	26.4	22.6
		10	65.1	54.7	46.2	40.3	36	32.8	29.2	24.9
		12	70.5	59	50	43.6	39	35.5	31.6	27.0
		16	81	67.8	57.4	50	44.7	40.7	36.2	30.6
		20	89	74.8	63.3	55.3	49.3	44.9	40	34.1

The auxiliary shaft must occupy a specified position at the end of the one revolution. A special device controlled by cam K controls this positioning function.

The machine cycle is shown in Figure 20. The actual cutting, together with the dwell, occupy 195° on the curve of cam A, which is 54 % of the total. Idle movements, retraction of the cutter and indexing, occupy the remaining 165° (46 %). As a time-saving measure, the idle movements controlled by cams B and C start somewhat before the termination of the milling and cutter retraction. The engagement of the ratchet-wheel teeth by cam C, for example, takes place in the interval 150° – 210°. The auxiliary-shaft cams perform auxiliary operations connected with the replacement of blanks in the dividing-head collet.

The recommended feeds and cutting speeds for face teeth (module and oblique) are given in Tables 11 – 12.

Technical data on the S-186 gear miller

Maximum diameter of the wheel milled, mm	25
Maximum milling depth, mm	3
Maximum module, mm	1
Number of teeth milled	From 4 to 36
Maximum cutter diameter, mm	12
Cutter-spindle speed, rpm	1150
Vertical cutter-table travel, mm	3-6
Camshaft speeds, rpm	15, 20, 25.7, 35.4, 45.8, 60
Auxiliary-shaft speed, rpm	15
Electric-motor power at 1400rpm, kw	0.4
Limit of adjustment of the vertical table travel, mm	13
Maximum angle of swivel of the cutter-spindle head, degrees	5
Feed per cutter revolution	0.047-0.6
Milling speed, m/min	45

The establishment of the cutting conditions and the calculation of the machine production rate are done in the same way as for the S-40 miller. The maximum cutting speed for the machine is 45 m/min. The milling allowances are between 0.05 and 0.15 mm, depending on the module and the number of teeth. The quality of the surface finish is class 7 or 8.

MILLING TEETH BY THE GENERATION METHOD

Milling by generation is a more advanced and more productive method of gear manufacture than is form milling. The generation methods in use, in dependence on the design of the cutting tool, are: generation by rack tool, gear shaping, and gear hobbing.

The basis of the hobbing method lies in the simultaneous rotation of the hob spindle and the work spindle, coordinated in such a way that each rotation of the hob spindle corresponds to the $\frac{1}{z}$ part of a work-spindle rotation, where z is the number of teeth on the wheel being milled (Figure 21).

The required relationship between the speeds of rotation of the hob and part is obtained by means of change gears in the hobbing-machine gear train.

In addition to the rotary motions of the hob and part, the machine table (or the hob slide) is fed axially along the work in order to mill the length of the tooth.

In the time that the wheel rotates by one circular pitch (tooth plus space) a single-thread hob accomplishes one rotation. Obviously, the axial lead of the hob thread (the distance between two threads in the axial cross section) must be equal to the circular pitch of the wheel. This is the basic condition for the relationship between the hob and the gear to be milled – the linear equality of the hob lead and the gear pitch.

In the case of a multi-thread hob, one revolution of the hob will correspond to $\frac{i}{z}$ revolutions of the gear, where i is the number of threads on the hob.

The hobbing method is used in watch production for milling wheels and pinions with more than 12 teeth.

Involute wheels of the same module but with different numbers of teeth are all milled by the same hob. The involute profile thus makes it possible to standardize the cutting tool. Watch-gearing profile wheels and pinions are each milled by a special hob.

The hobbing method is not universal, as not all gears can be hobbed. When involute gears with a small number of teeth are hobbed, undercutting occurs (Figure 22). Undercutting is present when the point A on the profile of the hob tooth is nearer to the gear center than point B (the point at which the line of action BP is tangent to the base circle of the gear, of radius r_0). Considerable undercutting reduces the working length of the involute and thus disturbs the smoothness of operation of the gearing. In particular cases, undercutting reduces the tooth strength.

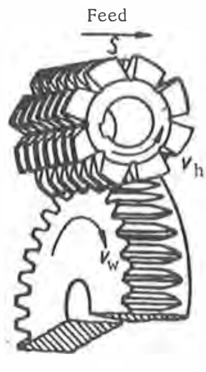


FIGURE 21. Diagram of hobbing

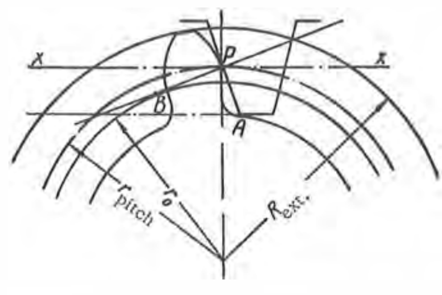


FIGURE 22. Undercutting of an involute tooth for $z < 14$

In the case of standard 20° involute gearing, undercutting will occur when gears with fewer than 17 teeth are hobbed. However, hobbing is considered as acceptable for gears with as few as 14 teeth, since the undercutting is negligible in that case and the tooth face of the mating gear can be made with a circular arc or some other curve instead of an involute. The transmission will not be correct in the modified sector, but another pair of teeth can be meshed simultaneously to negate the error.

Profile correction is used to reduce the undercutting at the tooth root in hobbing. The correction consists in increasing the center distance of the meshing pair by $\Delta A = \frac{14 - z}{17} m$ (this is acceptable on the basis of design consideration). The hob is withdrawn from the blank center by this same distance, thus increasing the blank radius. In this way the point A on the hob is withdrawn beyond the point B or to a point near B. When the hob is thus withdrawn **its** pitch line XX will no longer be tangent with the wheel design pitch circle r_p. The hob pitch line will be tangent with a circle of radius $r_p + \Delta A$. The form of the involute is not altered when the center distance is increased as it depends on the base circle. The active sector of the involute becomes less steep, a fact which improves the properties of the gear pair and leads to more uniform wear on the profiles. The involute gearing in accurate instruments which require high gear efficiency is corrected according to this method. If a correction is impossible, wheels with fewer than 17 teeth should be form-milled. The design drawing must take into account the necessity of correction.

When hobbing watch-gearing profile pinions with between 6 and 12 teeth, the acute tip of the hob tooth (at an unfavorable depth-to-width ratio) is rapidly worn, and the tooth space obtained has an incomplete depth (Figure 23).

The 530 semiautomatic gear-hobbing machine was designed for hobbing small-module spur gears and pinions and is locally produced. The machine is available in several versions and can operate automatically.

The kinematic scheme of the machine is given in Figure 24.

Power from the electric motor is transmitted through a V-belt from the three-step pulley (1) to the three-step pulley (2) on the driveshaft I. One end of the driveshaft is connected through a telescoping shaft to the hob spindle. The work-spindle change gears are connected to the second end of the drive shaft. The change gears (a, b, c, d) drive the worm shaft II, which carries a single-thread (or five-thread) worm (3), and which in turn drives the work-spindle worm gear ($z = 50$). The use of a single-thread worm makes it possible to obtain gears of high angular-pitch accuracy, while the use of a five-thread worm makes it possible to mill pinions with 6 teeth, thus considerably increasing the range of this machine (most watch-mechanism pinions have between 6 and 12 teeth).

The work spindle carries, in addition to the worm wheel, an 18-tooth helical gear which meshes with a 60-tooth helical gear on shaft III. The feed change gears z_1, z_2 are located on the shaft III and the worm shaft IV.

The worm shaft IV carries a single-thread worm which drives the worm wheel H fastened to the feed shaft V. A 14-tooth helical gear, permanently meshed with a rack, is fitted to the right end of shaft V.

The rack is fastened to the machine slide. The 14-tooth helical gear can grip the shaft V by means of a conical bushing and rotate together with it, forcing the slide to advance. When the link between the conical bushing and the gear is released (by manual action) the latter sits freely on the shaft, and the slide does not move.

The slide is returned after hobbing by means of two springs located inside the bed.

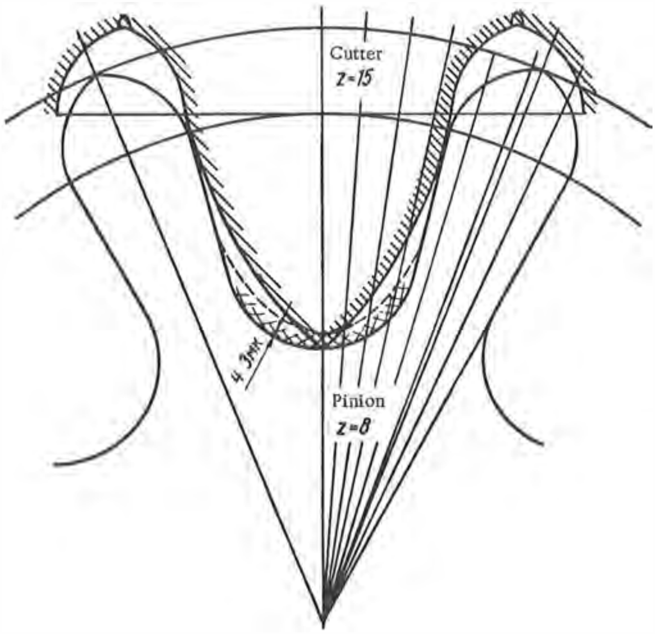


FIGURE 23. Insufficient tooth space as a result of the blunting of the hob tooth

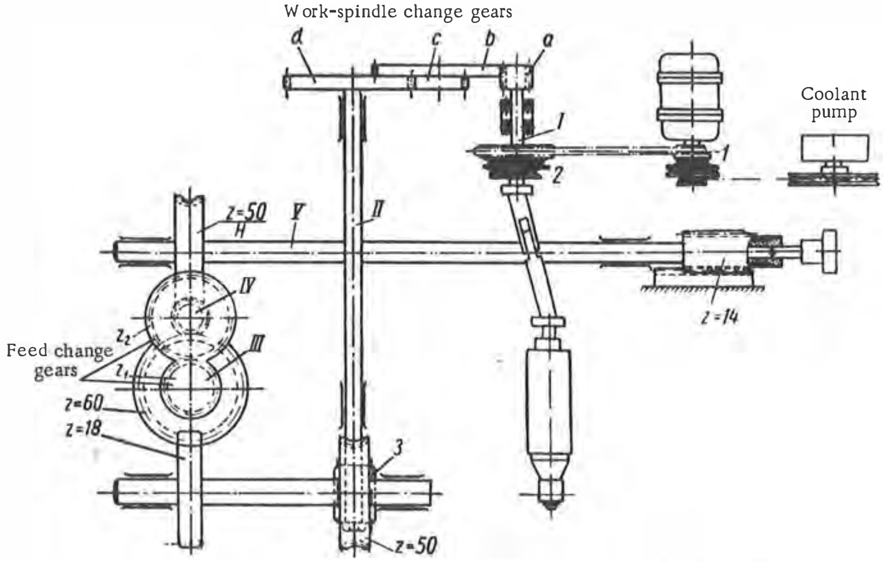


FIGURE 24. Kinematic scheme of the 530-machine model

The work-spindle change gears are selected according to the following formula:

$$\frac{a}{b}\,\frac{c}{d}=\frac{50}{z},$$

where z = the number of teeth on the wheel to be hobbed.

The following equality exists for a constant center distance for gears a and b:

$$z_a + z_b = 125,$$

(the sum of the numbers of teeth on gears a and b is 125).

Three or four gears can be used:

When working with three gears a-b-d:

$$\begin{array}{ll} & z \qquad z \\ a = 50 & 25; \\ b = 75 & 100; \\ d = z_{\text{cut}} & \frac{z_{\text{cut}}}{2}. \end{array}$$

When working with four gears a - b - c - d:

$$\begin{array}{ll} & z \qquad z \\ a = 50 & 25; \\ b = 75 & 100; \\ c = 25 & 50; \\ d = \frac{z_{\text{cut}}}{3} & \frac{z_{\text{cut}}}{4}. \end{array}$$

The gears available for the machine are:

1) a set of 93 change gears d, beginning with z = 24, 36, 40 and up to z = 130;

2) two step gears b/c = 75/25 and 100/50;

3) two gears for a and c, z = 50 and z = 25.

When working with three gears $a-b-d$ the gear b serves as an idler only, reversing the direction of rotation of gear d.

The feed gearing consists of two change gears z_1, z_2. Six pairs of change gears provide six feed steps between 0.1 and 1.35 mm per blank revolution.

The feeds corresponding to different combinations of the change gears are given in Table 13.

The number of feed steps can be increased by the use of additional gears z_1, z_2.

The three-step belt transmission from the motor to the driveshaft provides three hob speeds. Since the electric motor itself has two speeds, the total number of hob-spindle speeds is 6.

The motor pulley has a fourth step for powering the coolant vane pump.

The telescoping shaft makes it possible to feed the hob slide in the vertical and in two horizontal directions.

TABLE 13

Feed gearing

Feed, mm per blank revolution	Gears	
	z_1	z_2
0.10	24	84
0.20	36	72
0.30	48	60
0.45	60	48
0.75	72	36
1.35	84	24

TABLE 14

Hob-spindle speeds and cutting speeds

Hob-spindle speed, rpm	Cutting speed, m/min, for cutter diameter D = 24 mm	Speed of electric motor, rpm
500	37.8	1400
700	52.8	1400
1000	75.5	1400
1400	105.5	2800
2000	150.8	2800

Technical data, model 530 machine

Maximum work diameter, mm	
automatic operation	25
semiautomatic operation	50
Maximum hobbing length, mm	40
Number of teeth hobbed	6-100
semiautomatic operation	6-300
Maximum module, mm	1
Minimum module, mm	0.05
Hob diameter, mm	25-30
Hob spindle tilt, degrees	Up to 3°
Electric motor power, kw	0.65

Hob cutters. Involute gears are cut by hobs having straight-sided rack teeth according to GOST 3058-45. This tooth profile is called the basic rack (Figure 25). Watch-gearing profiles are hobbed, as previously mentioned, by special hobs designed for each wheel. Since this method is used in one of the most advanced branches of precision-instrument manufacture, the design of hobs is a practical necessity, and we shall therefore dwell on the subject in greater length.

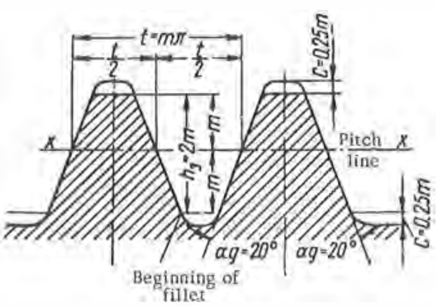


FIGURE 25. Basic rack

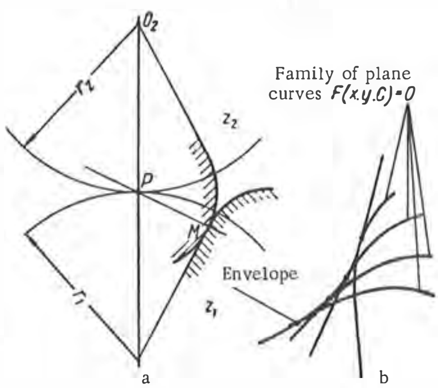


FIGURE 26. Envelope of the family of plane curves – mated profile

According to the general theory of gearing, the active portions of the profiles of a meshed pair must be conjugate in their relative motion. If we imagine the gear z_1 in contact with gear z_2, so that their pitch circles roll without sliding (Figure 26, a), then the successive positions of the gear-tooth profile generate a family of plane curves on the fixed plane fixed to gear z_2, (Figure 26, b). According to the general theory of gearing, the envelope of this family of curves is the mating gear-tooth profile, desired since: 1) each point on the envelope is a point on one of the curves of the family of curves, and ,

2) each point on the envelope is the limiting position of the intersection of two adjacent curves of the family when they are drawn infinitely near to one another.

As the hob revolves (see Figure 21) its tooth profile generates a family of plane curves on the fixed plane connected with the gear being milled. The envelope of this family is the mating gear-tooth profile and the envelope of the family of curves generated by the gear-tooth profile is the hob profile. Therefore, the determination of the profile of the hob tooth reduces to finding the envelope of the family of curves of the gear tooth when the pitch circle of the gear rolls without sliding on the pitch curve of the rack.

Several plotting methods exist for obtaining the mating tooth profile of the hob. The most widely used among them are the method of graphical generation and the graphical-analytical method.

The method of graphical generation is the simplest and most easily visualized of all the graphical methods. It not only makes it possible to plot easily and rapidly the desired profile, but is suitable for checking the results against the initial profile.

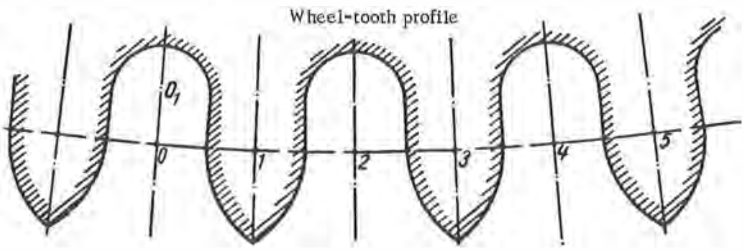


FIGURE 27. Gear-tooth profile

The procedure is as follows: the tooth-space profile of the gear is drawn to a large scale on a sheet of paper. The pitch circle is divided into several equal parts, and the points of division are numbered as shown in Figure 27. Radial straight lines are drawn through the division points. A straight line is drawn on tracing paper (Figure 28) and taken as the hob pitch line. This straight line is divided into parts of length equal to that of the arcs of the pitch circle between the division points and the points obtained are numbered in the same way as on the pitch circle. Perpendiculars to the straight line are drawn at the points of division. The tracing paper is then superimposed on the sheet in such a way that the zero point and the perpendicular on the tracing paper coincide with the zero point and the radial straight line on the sheet. The tooth-space profile is then drawn on the tracing paper. Next, the corresponding points to the right and left on the two sheets are consecutively brought into coincidence, and the tooth space profile is drawn each time on the tracing paper.

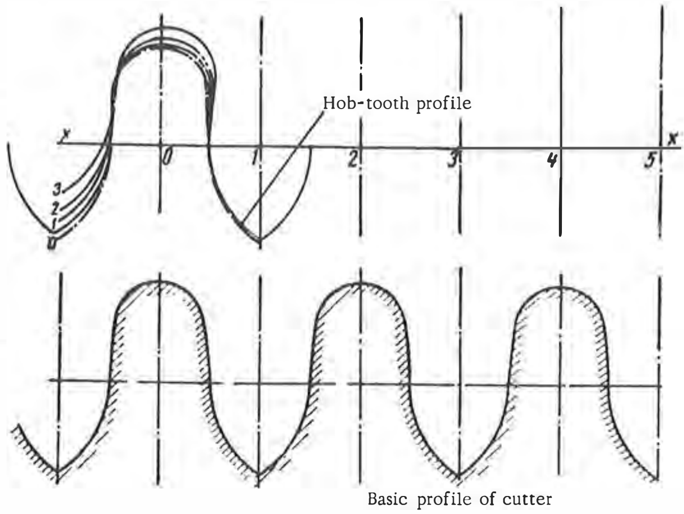


FIGURE 28. Hob-tooth profile

The envelope of the family of curves obtained is the required hob-tooth profile. The plotting of the required profile reduces to selecting the arc radii for each portion of the envelope. The correctness of the profile obtained is checked by a reverse generation. The pitch circle of the gear is drawn on the tracing paper, divided into the same number of parts as in the preceding case, and the tracing paper is then superimposed on the sheet. By drawing the profile of the hob tooth in every position one obtains a family of curves whose envelope must correspond to the original gear tooth-space profile. The results are checked by superimposing the tracing paper on the initial profile drawn on the sheet. The method of graphical generation has a shortcoming in that it is difficult to draw the pitch circle on the sheet to a large scale. Figure 29 shows the profile of a hob tooth, designed by the method of graphical generation, for hobbing a pinion with $z = 3$ and $m = 0.099$ mm.

The graphical-analytical method is used in cases where it is necessary to plot the profiles to a large scale. It consists basically in plotting the pitch circle of the gear as points whose coordinates are calculated analytically, and drawing the profile graphically from the given radius. The mating hob-tooth profile is plotted by the method of graphical generation.

A typical hob design for hobbing wheels of module 0.05 to 0.3 mm is given in Figure 30. It should be noted that the lead angle is 0°15' to 0°30'. The profile of the tooth in the normal plane can therefore be considered identical to its profile in the axial plane. This substitution will be unacceptable for lead angles above 0°30', as the difference in profiles will then be considerable.

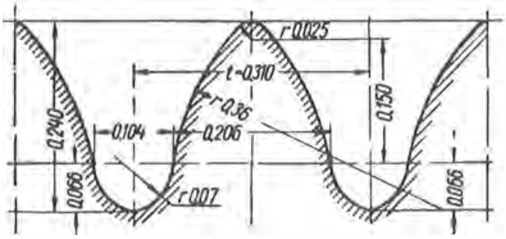


FIGURE 29. Hob-tooth profile for hobbing pinions with z = 8, m = 0.099 mm

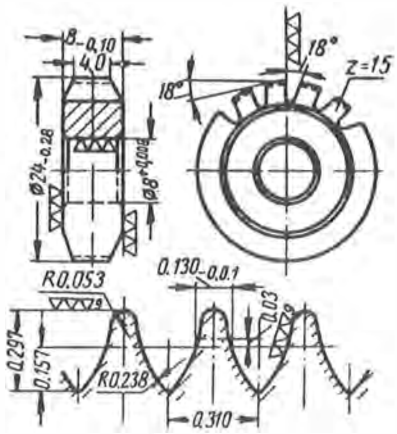


FIGURE 30. Dimensions of a watch-gearing-profile hob

The following maximum manufacturing errors are allowed according to the specifications for hobs of module 0.05 to 0.3 mm (Table 15).

TABLE 15

Tolerances and deviations in hob manufacture

Cutter errors	Permissible errors, mm	
	Class A	Class B
Outside-diameter run-out	0.01	0.02
Tooth-face run-out	0.005	0.010
Lead variation per turn	±0.002	±0.003
Total lead variation for five turns	±0.005	±0.008
Profile deviations:		
a) module smaller than 0.15 mm	0.003	0.005
b) module between 0.15 and 0.3mm	0.004	0.007
Tooth-space bottom blunting radius r	0.01	0.015

Hobs are form-relieved in special machines. Since watch-gearing modules have calculated values with three decimal figures (thus, the module of the fourth wheel of the "Pobeda" brand watches is m = 0.099 mm), the pitch adjustment of the machine is realized by means of a special device with a reading accuracy of 0.001 mm. The form-relieving is performed in three operations: initial roughing, final roughing, and finishing. The allowance for finish form-relieving is 0.01 mm per side.

The time norm for the manufacture of a hob is 6 to 7 hours, with 3.5 to 4 hours of this time taken by form-relieving.

The life of a hob before regrinding is, when milling brass gears, 8 to 10 milling hours.

Hobbing is used, as mentioned earlier, for milling wheels and, sometimes, pinions.

The mounting and positioning of pinion and wheel blanks in the model 530, and T-84 machines is similar to the mounting and positioning in the S-40 and S-53 machines (see Figure 7).

The cutting speeds and feed rates are established as a function of the mechanical properties of the material, the dimensions of the blank and the hob material. The feed rate in hobbing is expressed in millimeters per revolution of the part being hobbed and is determined by the following formula:

$$s_0 = C_s \cdot M^a z^b \text{ mm/rev.}$$

where s_0 = the feed in mm per blank revolution;
C_s = a factor depending on the mechanical properties of the material;
M = the module;
z = the number of teeth on the wheel or pinion being hobbed.

The values of the factor C_s and the exponents a and b are given in Table 6.

The cutting speed is determined by the formula

$$v = \frac{C_v}{M^x \cdot s_0^y} \text{ m/min.}$$

The values of the factor C_v and the exponents x and y are given in Table 7.

As a time-saving measure, the cutting speeds and feed rates recommended for hobbing watch-gearing wheels and pinions are given in Tables 16-20.

The hobbing (basic) time T_h is determined by the formula

$$T_h = \frac{L \cdot z_p}{n \cdot s_0 \cdot k},$$

where z_p = the number of teeth on the hobbed part;
n = the speed (rpm) of the single-thread hob;
k = the number of parts machined simultaneously;
s_o = the feed per blank revolutions;
L = $l + l_1 + l_2$, = the travel, where l = the length of the hobbed part (or of the several simultaneously machined parts), l_1 = the cutter approach (according to the table in Appendix 3), l_2 = the overtravel (1 - 1.5 mm).

The value of l_1 can be determined from the formula

$$l_1 = \cos\beta\sqrt{h_0(d - h_0)} + 1{,}5\tan\beta(m\sqrt{z} + h_0),$$

where β = the hob lead angle.

In the case of hobs, the value of the angle β does not exceed 0°30', as seen in Figure 30, and therefore $\cos\beta \approx 1$, $\tan\beta \approx 0$.

This reduces the formula to

$$l_1 = \sqrt{h_0(d - h_0)} \quad \text{[see formula (3)]}$$

The time T_h, calculated as necessary for the manufacture of one part, is compared with the available work-spindle speeds and the time per revolution closest to T_h is selected.

TABLE 16

Feed s_0, mm/blank revolution, for hobbing wheels and pinions made of U7AV and U10A steels

Number of wheel- or pinion teeth	Module, mm					
	0.10	0.12	0.15	0.20	0.25	0.30
8	0.08	0.085	0.10	0.11	0.13	0.14
10	0.085	0.09	0.11	0.12	0.14	0.15
15	0.09	0.10	0.12	0.13	0.15	0.17
20	0.10	0.11	0.13	0.14	0.17	0.18
30	0.11	0.12	0.14	0.16	0.19	0.20
40	0.12	0.13	0.15	0.17	0.20	0.22
50	0.13	0.14	0.16	0.19	0.21	0.23
60	0.14	0.15	0.17	0.20	0.22	0.24
70	0.145	0.16	0.18	0.21	0.23	0.25
80	0.15	0.17	0.19	0.22	0.24	0.26

TABLE 17

Cutting speeds v, m/min, for hobbing wheels and pinions made of U7AV steel

Feed s_0, mm/blank revolution	Module, mm					
	0.10	0.12	0.15	0.20	0.25	0.30
0.05	128	118.6	108	96	86.7	80.6
0.08	106	97.5	89	78.4	71.4	66
0.10	95	88.4	80.3	71.2	64.7	60
0.12	88	81	74.1	65.7	59.6	55.2
0.15	81	75	68.5	60.5	55	51
0.20	71	65	59.4	52.7	47.8	44.3
0.25	63.8	59	54.2	48	43.4	40.4
0.30	58.7	54.3	49.7	43.8	40	37
0.40	52.2	48	44.1	39.1	35.3	32.8

TABLE 18

Cutting speeds v, m/min, for hobbing wheels and pinions made of U10A steel

Feed s_0, mm/blank revolution	Module, mm					
	0.10	0.12	0.15	0.20	0.25	0.30
	Cutting speed v, m/min					
0.05	117	108	98.5	87.3	79	73.5
0.08	96	88.6	81	71.4	65	60.2
0.10	87	80.5	73.2	64.2	59	54.6
0.12	80	73.8	67.5	59.8	54.4	50.3
0.15	74	68.3	62.3	55.1	50.1	46.4
0.20	64.2	59.2	54.1	48	43.6	40.4
0.25	58.2	53.8	49.3	43.6	39.6	36.8
0.30	53.5	49.4	45.2	40	36.4	33.7
0.40	47.5	43.8	40.2	35.6	32.2	29.9

TABLE 19

Feed s_0, mm/rev, for hobbing wheels and pinions made of LS63-3-OT brass

Number of wheel- or pinion teeth	Module, mm							
	0.10	0.12	0.15	0.20	0.25	0.25	0.40	0.50
8	0.15	0.17	0.19	0.22	0.26	0.28	0.33	0.36
10	0.17	0.19	0.21	0.24	0.28	0.30	0.36	0.40
15	0.19	0.21	0.23	0.26	0.30	0.33	0.40	0.45
20	0.21	0.23	0.26	0.28	0.33	0.36	0.45	0.50
30	0.23	0.26	0.28	0.30	0.36	0.40	0.50	0.55
40	0.26	0.28	0.30	0.33	0.40	0.45	0.55	0.60
50	0.28	0.30	0.33	0.36	0.45	0.50	0.60	0.65
60	0.30	0.33	0.36	0.40	0.50	0.55	0.65	0.70
70	0.33	0.36	0.40	0.45	0.55	0.60	0.70	0.80

TABLE 20

Cutting speeds v for hobbing wheels and pinions made of LS63-3-OT brass

Feed s_0, mm/blank revolution	0.1	0.15	0.2	0.3	0.4	0.5	0.6
v, m/min	205	191	181	172	164	158	153

As an example, we will calculate the cutting conditions and the production rate for a specific case on the model 530 semiautomatic machine.

It is required to hob the teeth of a barrel with z= 80, module 0.105 mm and material — LS63-3 brass (Figure 31).

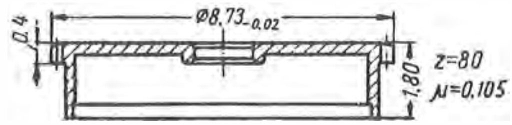


FIGURE 31. Wristwatch barrel

The number of parts machined simultaneously is k = 6.

We begin by writing down the data which are to be used in the calculation. We select from Table 19 the feed s_0 = 0.33 mm/rev., and from Table 20, the cutting speed v = 172 m/min. On the basis of the machine data we select the hob speed n = 2300 rpm. The length of the machined parts is (from Figure 31) l = 1.8 × 6 = 10.8 mm. The cutter approach is, from Appendix 3: l_1 = 2.3 mm. We fix the overtravel as l_2 = 0, since the overtravel is automatically provided by the turned-down diameter on the last part.

The total travel is L = 10.8 + 2.3 = 13.1 mm.

The hobbing time corresponding to the selected conditions will be

$$T_h = \frac{L \cdot z_p}{n \cdot s_0 \cdot k} = \frac{13.1 \cdot 80}{2300 \cdot 0.33 \cdot 6} = 0.23 \text{ min.}$$

The additional time necessary for changing the mandrel, starting the machine, and other similar operations is, according to the standards, 0.42 min, or 0.07 min per piece.

The calculated production rate for the machine per shift will be

$$A = \frac{480 \text{ min.}}{0.23 + 0.07} = 1600 \text{ pieces.}$$

We next compare the calculated data with the machine capabilities. The nearest value for s_0 is (from Table 13) 0.30 mm/rev., the nearest value of v is (from Table 14) 150.8 m/min at n = 2000 rpm.

The actual value of T_h will then be $T_h = \frac{13.1 \cdot 80}{2000 \cdot 0.30 \cdot 6} = 0.30$ min, instead of the calculated value of $T'_h =$ = 0.23 min. The actual production rate will be $A = \frac{480}{0.30 + 0.07} = 1300$ pieces per shift.

Comparison of the Form-milling and Generation (Hobbing) Methods

The following conclusions were drawn on the basis of investigations, conducted in watch production, of the accuracy and productivity of the two methods of milling teeth on wheels and pinions:

1. The productivity of the generation method is 1.5 to 2 times higher than that of the form-milling method. The generation method is inherently free of idle movements and no loss of time is incurred in indexing, so that the milling process is continuous. The basic milling time for milling the teeth on the center wheel of the "Pobeda" brand wristwatches is 0.123 min using the generation method and 0.278 min using the form-milling method (in two passes). The piece times are 0.19 min and 0.38 min, respectively.

The following are the time rates for the manufacture of formed cutters and hob cutters, and their respective service lives, according to data supplied by several watch plants:

	Time rate	Life (total)
1. Formed cutter	1 hour	10-12 shifts
2. Hob cutter	6-7 hours, 50% taken by form-relieving	20-25 shifts

The higher cost of hob cutters is compensated for by their longer life and the higher productivity of the generation method itself.

The manufacturing time rates for involute hob cutters are about 20% less than those for watch-gearing profile hobs.

The diffulty in manufacturing watch-gearing profile hobs lies both in the need to attain the specified accuracy of lead, profile and face run-out, and in the need to obtain a tooth space with minimum blunting radius. The teeth of hobbed wheels present a characteristic blunting of the tooth tip (Figure 32).

2. The surface quality obtained using the generation method is class 8 or 9 and is better by 1 or 2 classes than that obtained by the form-milling method.

Every roughness on the cutting edge of a formed cutter tooth is reproduced (in the negative) on the wheel-tooth profile. In the generation method, only those roughnesses are reproduced which appear on the line of action during generation. The surface quality, in both methods, may vary within the limits of one class, depending on the quality of sharpening.

3. Among the original machine errors the factor which has the largest influence on the accuracy of the completed gear wheel is the error in the

angular pitch of the index plate or in the work-spindle change-gear train in hobbing machines.

The angular-pitch accuracy of index plates is ±0°2'. This error increases to ± 0°3' during the life of the plate due to the nonuniform wear on its working surfaces.

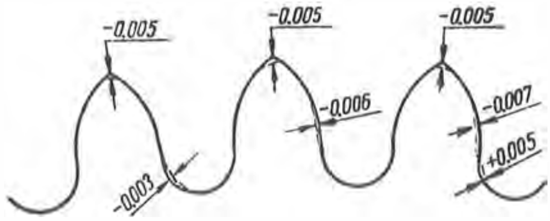


FIGURE 32. Blunting of the tooth tip in wheel hobbing

The accuracy of the work-spindle change-gear train of the model T-84, 530, and similar machines is also ±0°3'. It is thus seen that, from this point of view, both methods give identical results.

The two methods are equivalent with respect to the other accuracy parameters as well: profile, tooth thickness, outside diameter, and run-out. The run-out depends to a small extent on the method used. When using the form-milling method, the cutter must be accurately set relative to the part center – the center plane of the cutter must pass through the axis of revolution of the blank. No such positioning is required when using the generation method.

Rounding-up is a fitting operation. It is used in those cases where it is required to reduce the wheel run-out, or its outside diameter. The S-61 machine is used to perform this operation using a special cutter (Figures 33-34). One third of the cutter circumference is smooth and bent out of the general plane by the value of the tooth pitch of the wheel being worked. When the cutter revolves, the end of the deflected segment engages a tooth space on the wheel being worked and indexes it by one pitch. The remainder of the cutter circumference has very fine teeth with a profile identical with that of the wheel-tooth space. No horizontal or vertical feeds are imposed. The wheel, together with its shaft, revolves freely between the machine centers (Figure 35).

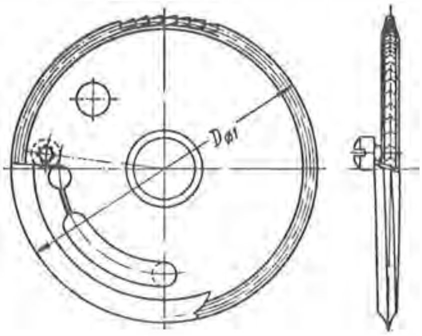


FIGURE 33. Rounding-up cutter

The necessity for rounding-up decreases with an increase in the accuracy with which wheels and pinions are machined, and with an increase in the accuracy of the assembly elements (interaxial distances in the plates). The sizing of holes in wheels, based on the outside diameter of the wheel, has made it possible to reduce the run-out of wheels to 0.01–0.015 mm, an accuracy sufficient for the normal operation of watch gearing.

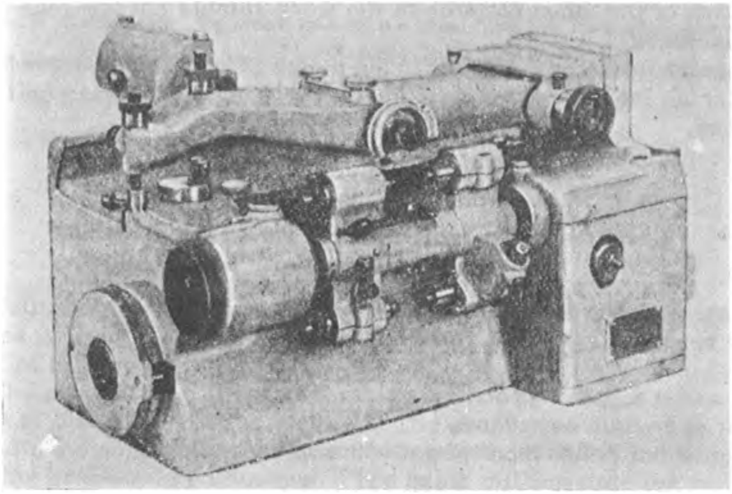


FIGURE 34. S-61 machine for rounding-up wheels

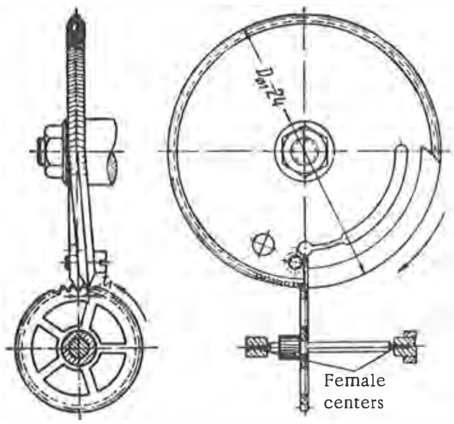


FIGURE 35. Position diagram of rounding-up cutter and wheel

INSPECTION OF GEARING ELEMENTS

Several methods exist for the inspection of the various gearing-elements, each with its specific advantages and shortcomings.

The inspection methods and means are as important in production as are the machining methods and means. Inspection-operation sheets are accordingly included in the technical documentation along with the machining-operation sheets by many plants. The inspection methods must obviously be quick, and the inspection means accurate and easily handled.

The various gearing elements are inspected in watch plants by means of contact and optical measuring methods. The measured errors being small in absolute value, the inaccuracy of the measuring method itself constitutes a considerable percentage of the tolerance. Thus, the accuracy of profile inspection by means of a profile projector at a magnification of 100× is not better than 3 μ, which is 30% of the tolerance on the tooth profile of an accuracy class 2 wheel with module between 0.1 and 0.15 mm.

The gearing elements listed in Table 2 are inspected by the inspection methods and means described below.

Inspection of the external diameter. The inspection of the external diameter is the first operation in the sequence of inspection operations for toothed-wheel elements. Any variation in this diameter leads, as was explained above, to a corresponding shift in the basic rack.

The external diameter is inspected, under plant conditions, by means of ring limit gages (Figure 36), and in individual cases by watch micrometers. The advantage of the gage-inspection method lies in the fact that it eliminates the possibility of passing wheels or pinions of diameters larger or smaller than required, and in that the number of teeth on the wheel or pinion plays no part in the inspection. This method is also very quick.

Measurement by a watch micrometer gives the actual wheel dimension, but difficulties are encountered when using this method for measuring wheels with an odd number of teeth. This method is also slower than the ring-gage method.

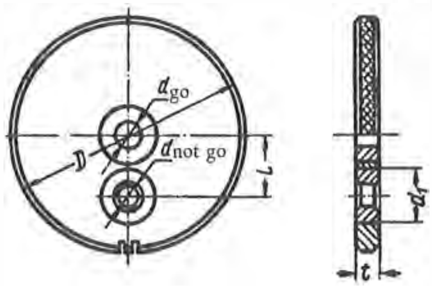


FIGURE 36. Ring gage

Samples of three wheels are inspected from each mandrel (one from each end and one from the middle).

In the case of pinions, one pinion is taken at random and inspected from among 10-15 produced.

The inspection of the external diameter under laboratory conditions is carried out using a tool microscope.

Measurement of the tooth thickness. The tooth thickness is measured using a watch micrometer with special inserts or using a tool microscope. In addition, the thickness is inspected by the profile projector simultaneously with the profile inspection. To that end, the projected tooth profile is superimposed on the properly scaled design drawing. The tolerance on the outside diameter being small, its influence on the accuracy of the measurements when using the superposition method is negligible. The method of profile projector inspection is also rapid.

In the case of wheels, the thickness of three teeth is measured while all the teeth are inspected with pinions. The inspection in both cases is a random inspection.

Inspection of the tooth profile. The third element subjected to inspection is the tooth profile. Profile inspection is always carried out using a profile projector with a magnification of 50× or 100×, and sometimes of 200×. The profile projector has become the accepted plant inspection means (Figure 37). The measurements are made more convenient and accurate by drawing the design profiles on glass.

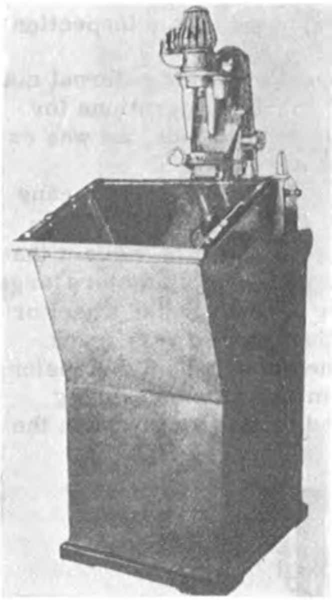


FIGURE 37. Profile projector with a magnification of 10×, 25×, 50×, and 100×

The tooth thickness is inspected simultaneously with the profile inspection. The profile inspection is of the random type. More accurate measurements are conducted using a profile projector with 200× magnification and an oversized screen.

Measurement of radial run-out. The measurement is conducted either by the contact method with the aid of a special indicator, or by the optical method, in which case the part is positioned on a coordinate-marking machine in a special device.

The inspection is performed under plant conditions using indicators with special inserts. Low-pressure indicators (up to 30 g) of this type are manufactured by the watch industry with divisions of 0.001 mm and a measuring range of ± 0.03 mm (Figure 20, Chapter X).

The method of inspection by a coordinate-marking machine, used in laboratories, is time-consuming. The achievable accuracy, according to the technical data of the machine, is 0.003 mm. This inspection operation can also be conducted by means of a profile projector. Wheels and pinions are random-inspected.

Measurement of the circular pitch. This element has only recently begun to be inspected. As long as the form-milling method was the prevalent manufacturing method in use, the measurement of the circular pitch was unnecessary because the tooth spaces were necessarily equal.

This system is inapplicable to hobbed wheels, since errors in the many gear trains of the machine influence both the tooth thickness and the tooth-space width. Therefore, with the wide adoption of the generation method, it became necessary to measure the circular pitch and to determine the difference between successive circular pitches (δ t). The measurement of circular pitches is conducted on a coordinate-marking machine with the aid of a circular table. The difference (δ t) is obtained by passing from angular to linear dimensions by the formula

$$\delta t = \frac{\delta \varphi'}{57°18'} \cdot r_{\text{pitch}}$$

The inspection is of the random type.

Chapter VI

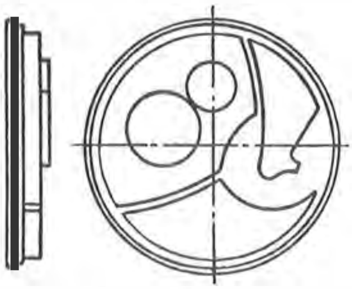
BASIC MACHINING OPERATIONS FOR PLATES, BRIDGES AND COCKS

The pillar plate is the foundation on which pocket- and wristwatches movements are mounted. The pillar plate is 2.30 to 2.75 mm thick, with recesses and projections of various shapes and heights, and with a large number of through and blind holes, some of them threaded.

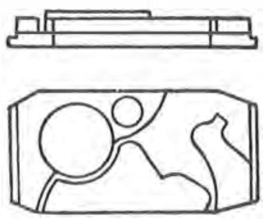
Plates have various shapes, depending on the general arrangement of the movement parts. A circular plate is used in pocket watches and in the majority of wristwatches. Certain brands of wristwatches, both men's and ladies', have plates of noncircular shapes: square, rectangular, beveled rectangular (Figure 1), barrel-shaped or oval.

The size of a watch is defined as the size of the mounting shoulder on the plate. A 26-mm size (K-26) watch has a mounting-shoulder diameter of 26 mm. In a 18-mm size watch (K-18) the mounting shoulder on the small side of the rectangle is 18 mm.

Figure 2, a is a photograph of the plate of a 26-mm size "Pobeda" brand wristwatch, and Figure 2, b is a photograph of the plate of an 18 mm size "Zvezda" brand wristwatch.



a



b

FIGURE 1. Plate shapes:

a–circular; b–beveled rectangular.

The dial side of the plate carries the motion work and the dial. The opposite side of the plate, called the cock side, carries the basic assemblies of the watch movement: the barrel, the train, the escapement and the balance. The movement assemblies are supported on the plate by means of cocks and bridges, which are plates 0.4 to 4.2 mm thick and with various configurations and having holes, recesses and projections of various shapes and heights for mounting the watch parts.

Wrist- and pocket watches usually have four main cocks and bridges: the barrel bridge which supports the barrel, the center wheel and the keyless (winding) wheels; the train bridge which supports the third, fourth and escape wheels; the pallet cock which supports the pallet fork; and the balance cock which supports the balance with the hairspring and regulator.

The large number of recesses in the plate, which overlap to a considerable extent, considerably weaken the plate cross section in certain operations and reduce its rigidity. A drawing of a wristwatch plate is given in Figure 3, a, while Figures 3, b, c, d show various sections. The wall thickness in section AA (drawing b) is 0.3 mm, while the total plate thickness is 2.35 mm. In section BB (drawing c) there is a stepped cylindrical counterbore with run-out tolerance 0.03 mm relative to hole III. In section CC there is a contoured through hole with recesses on both sides.

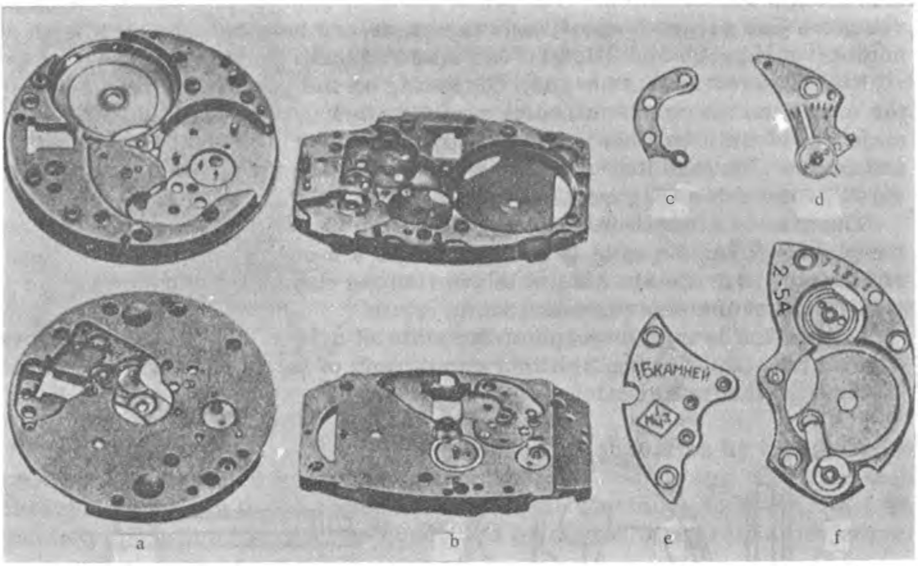


FIGURE 2. Wristwatch plates, cocks and bridges

a–dial and cock sides of the plate of "Pobeda" brand watches; b–dial and cock sides of the plate of "Zvezda" brand watches; c–pallet cock; d–balance cock; e–train bridge; f–barrel bridge.

The various contoured recesses must be very accurately made. The width between the restricting projections for the pallet fork must be 1.381 ± ± 0.005 mm (drawing e). The tolerance for the holes for the journals, pinions, and cock pins must not exceed 0.005 mm. The tolerances for the center distances of gear pairs, and escapement and balance assemblies must not exceed 0.0075 to 0.01 mm. Corresponding holes in plates and cocks assembled in stacks must be true (concentric), and the location deviations must not exceed the center-distance tolerances.

The surface-finish quality of the holes for axes, arbors and pins must correspond to class 9 – 10 and the finish quality of the cock side of the plate and of the cocks themselves must be class 8. The surface quality of the remaining, less critical, parts must be no poorer than class 7.

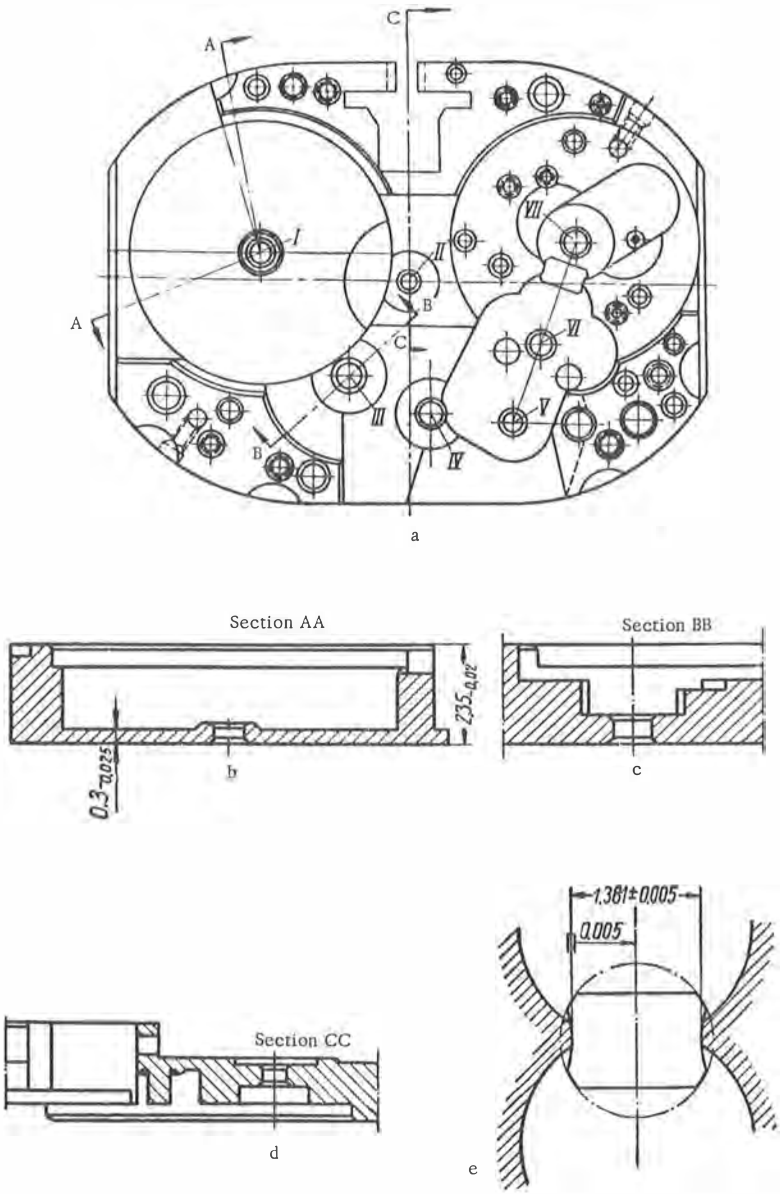


FIGURE 3. Wristwatch plate (cock side):

a–general view; b–section AA; c–section BB; d–section CC; e–banking projections for the pallet fork.

The plate and bridges are made of a special brass, type LS63-3.

The rigid and diverse requirements relative to watch plates and cocks (bridges) have led to the development of suitable machining processes. Sixty operations are involved in the process of machining the plate: blanking, contour shaving, center punching (pointing), drilling holes according to the center-punch marks and tapping them, turning and counterboring, milling recesses and shoulders, and shaving the holes.

The machining of bridges is simpler, but includes the additional operations of marking and texturing.

The plate-machining operations are divided up as follows: 20% stamping operations, 35% drilling operations, 30% turning and milling operations, 15% shaving and cleaning operations, and aging.

The stamping operations: blanking, shaving and center punching, were described in Chapter III (stamping operations). The other operations are described below.

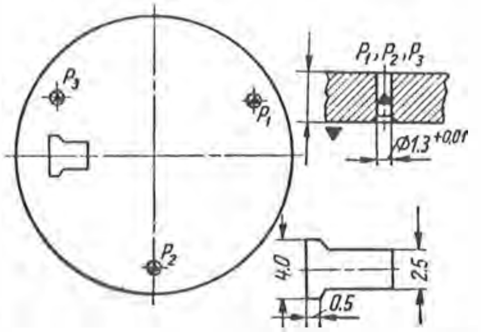


FIGURE 4. Base holes P_1, P_2, P_3 on the "Pobeda" brand wristwatch pillar plate

The machining of the plates is carried out with reference to three base holes P_1, P_2, P_3 (Figure 4). Before these holes are shaved the plate is blanked and contour-shaved. The winding-pinion window is pierced and center-punch marks for the three base holes are made. After stress-relieving, the three base holes are drilled and countersunk and the plate is turned on both the cock and the dial sides. The plate of "Pobeda" brand wristwatches, shown in Figure 4, is subjected to further machining after these preparatory operations.

The stepped holes for the fitting pins, situated on the dial side of the plate, are machined first. The largest diameter is drilled first (Figure 5, a), in order to decrease the thickness which remains to be pierced by the small-diameter punches. The smaller holes are then pierced, and the next group of holes are simultaneously center-punched (Figure 5, b). An allowance of 0.10 – 0.15 mm is left for subsequent shaving of the holes. Now the plate is machined. Center-punched holes, designated in the drawing by the symbols S, B, 7, etc., are then drilled, counterbored, countersunk and bored (Figure 5, c).

The drilling is followed by preliminary counterboring of the barrel recesses and the milling of recesses for the train*, escapement and balance.

* Train — the toothed-wheel transmission connecting the barrel with the escapement.

The plate deforms (buckles) as a result of the considerable local removal of metal and it accordingly undergoes a stress relief operation after which the dial side of the plate is either turned or shaped. Plates and cocks (bridges) are stress relieved in the PN-316 electric pit furnace at 230 – 250°C for 2 hours.

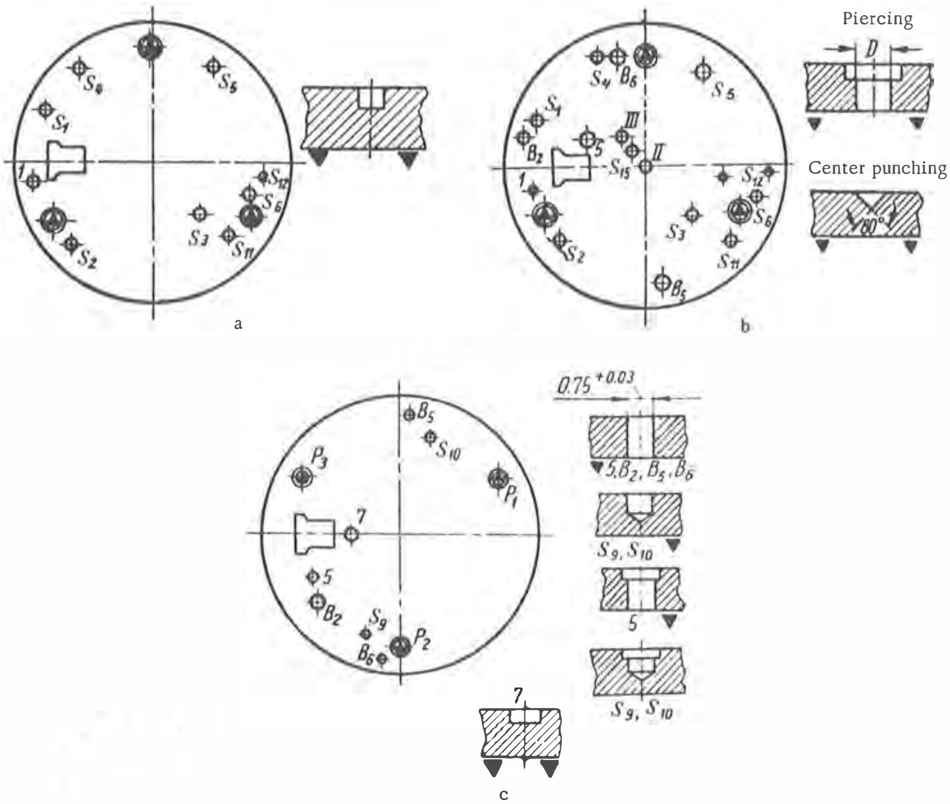


FIGURE 5. Pin holes in the plate

a–preliminary drilling; b–punch-piercing of holes with simultaneous center punching of a group of other holes; c–machining the center-punched holes.

Finish milling of the recesses for the train, escapement and balance, and the boring of the stepped barrel recess follow. These operations bring the plate to the shape shown in Figure 6.

Next, 14 holes are rough-shaved leaving an allowance for the finish shaving and the remaining 15 holes are pierced (Figure 7).

The holes for the winding stem and the fastening screws of the dial feet (Figure 8) are then machined. Finally, 24 holes for the cock and bridge fitting pins and for the train, escapement and balance arbors are shaved (Figure 9).

The machining of the recesses and projections on the dial side of the plate for the winding gear and the motion work is now performed (Figure 10). The windows for the winding pinion and the claw clutch are shaved.

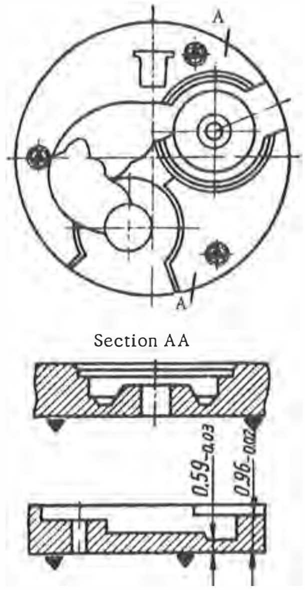


FIGURE 6. View of the "Pobeda" brand watch plate after machining the recesses from the cock side

FIGURE 7. Disposition of the holes in the plate (view from the cock side)

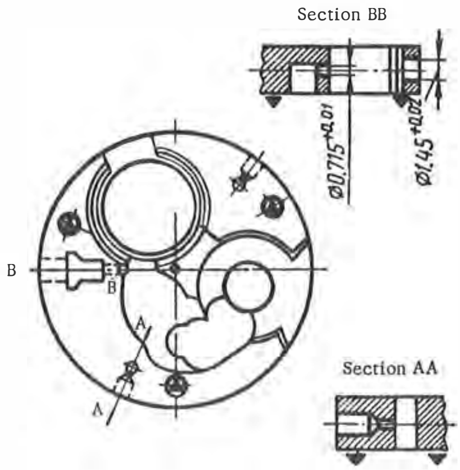


FIGURE 8. Lateral holes in the plate

The holes are countersunk from the dial and cock sides, and threads are tapped in holes from both sides. A shoulder is turned for mounting the case (Figure 11); and finally, the cleaning operations are performed.

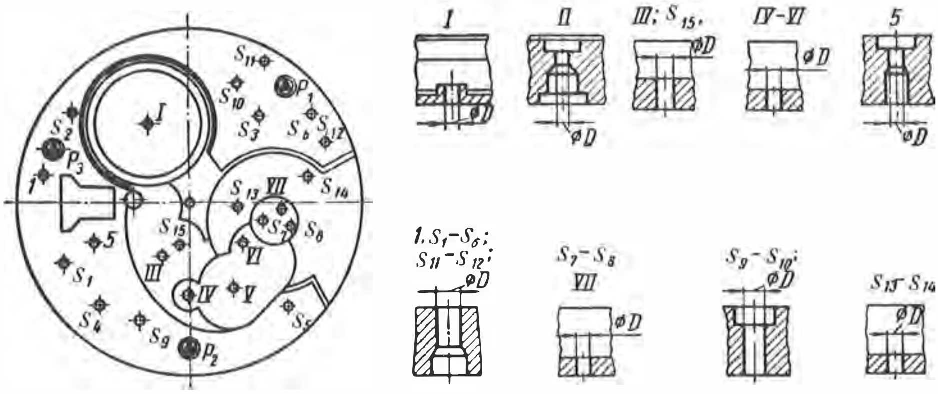


FIGURE 9. Plate holes after shaving. The hole diameters are: $1-0.056^{+0.012}$; $S_1-S_6-1.282^{+0.005}$; $S_7-S_8-0.505^{+0.005}$; $S_9-S_{10}-0.95^{+0.02}$; $S_{11}-S_{14}-0.535^{+0.005}$; $S_{15}-0.49^{+0.005}$; $\mathrm{I}-1.01^{+0.005}$; $\mathrm{II}-0.655^{+0.005}$; III, IV, V, $\mathrm{VI}-0.982^{+0.005}$; $\mathrm{VII}-1.182^{+0.005}$; $5-0.54^{+0.005}$.

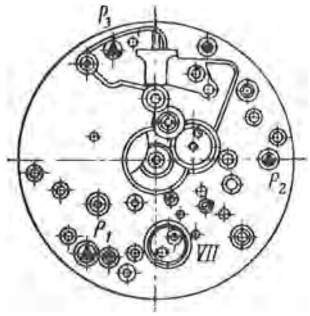


FIGURE 10. Plate recesses (view from the dial side)

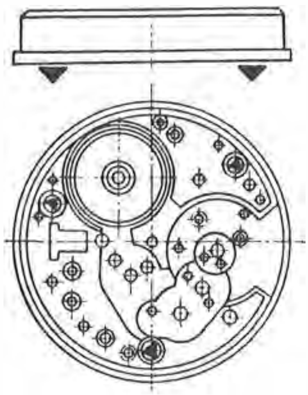


FIGURE 11. View of the plate from the cock side after the completion of all machining operations

TURNING AND SHAPING OF FACE PLANES AND BORING OF RECESSES

The face planes of plates, cocks and bridges are faced in order to provide a more accurate mounting and positioning base for the subsequent mechanical operations. The surfaces are faced either by turning on the S-81A semiautomatic lathe, or by shaping on the S-188 rotary shaping machine.

The S-81A two-spindle semiautomatic lathe (Figure 12) consists of the base (1), housing the drive, the camshaft housings (2), the headstocks (3) and the slides (4).

The base (1) of the machine is a light cast-iron block of rectangular form. The electric motor is mounted on a plate inside the base (at its center). A flange mounting the camshaft drive is mounted on the back wall in the lower part of the base.

The camshaft housing (2) is a complex iron casting, inside which are mounted the countershaft, the transmission shaft, and the shaft for the right-hand and left-hand slides. The housing is fastened to the base by means of screws and serves as base for the two headstocks and the two slides.

The headstock (3) is the main assembly of the machine and is housed in a cast-iron body (1) (Figure 13). The hollow spindle (2) is mounted in two bronze bearings. The spindle pulley revolves freely on ball bearings and powers the spindle through the cone of the friction clutch (4) which is pressed against the pulley cone by four springs (5) and connected with the spindle through the keyed sleeve (6).

When the machining cycle is ended, the frictional clutch is disengaged by the cone being moved to the right, along the key, by the lever (7) which is controlled by cam (19) on the camshaft (see Figure 15). When the machining cycle begins again, the friction clutch is freed and engages the pulley again, under the action of springs (5), thus starting the spindle.

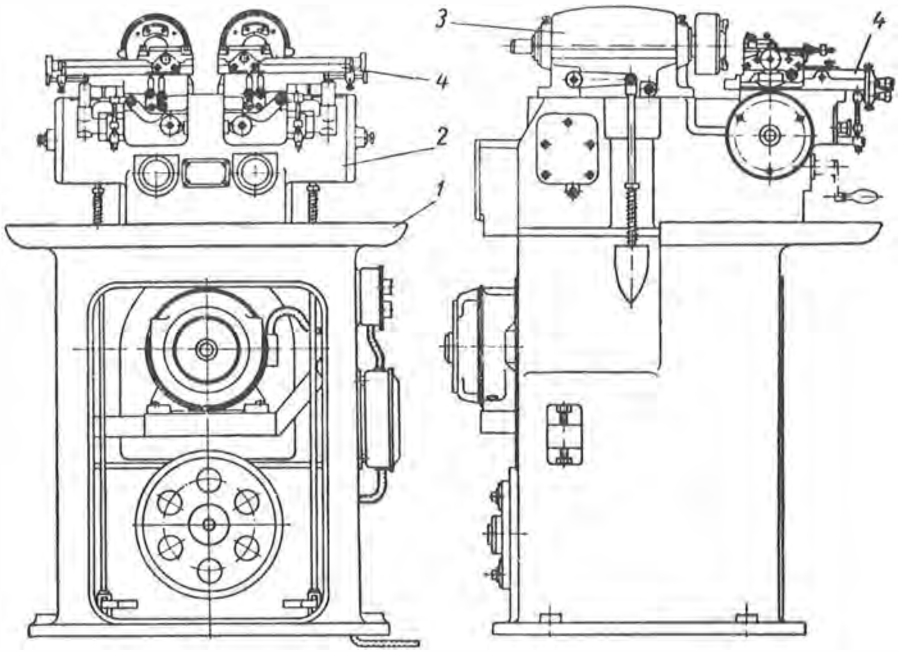


FIGURE 12. General view of the S-81A two-spindle semiautomatic lathe:

1-base; 2-camshaft housing; 3-headstock; 4-slides.

The plate is gripped in the collet chuck (8). Contour plates (10) are fastened to the collet face (9) in order to hold the shaped parts on their contour. When the foot pedal is pressed, the sleeve (11) is moved to the right by a fork. The stop levers (12) are thereby freed to open under the action of the bar spring (13). The bar (14) advances to the right together with the collet (9), thus opening the collet and freeing the part. After the machined part has been unloaded and the next part to be machined has been positioned, the foot pedal is released, the sleeve is returned to the left by the springs (15) and presses on the right-hand ends of the stop levers. The stop levers force the bar back (by pressing on its shoulder) and the collet grips the part.

The collet is threaded to the bar and is positioned in the chuck by means of the pin (16).

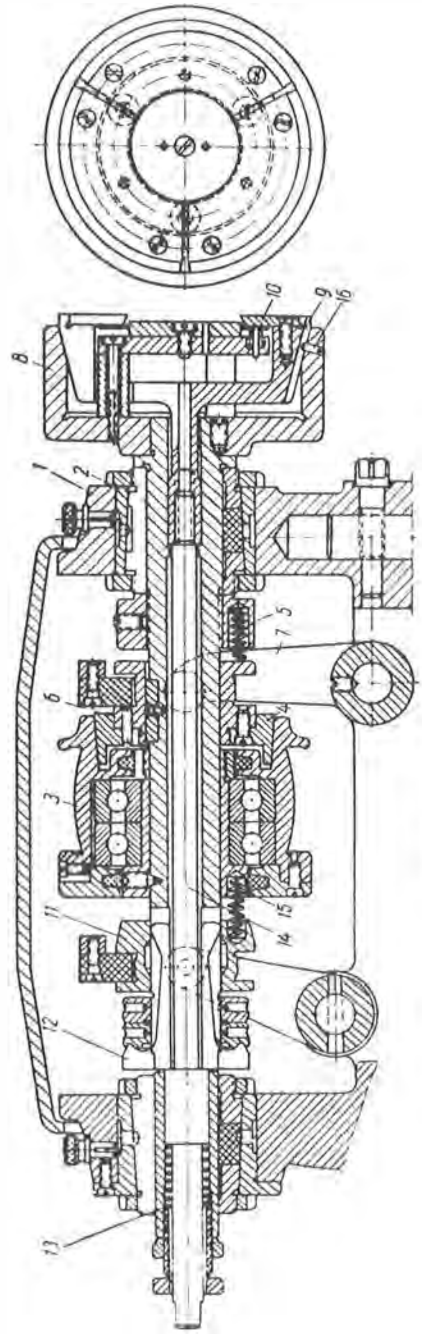


FIGURE 13. Headstock of the S-81A machine

The camshaft housing carries guides along which the right-and left-hand slides can move longitudinally (Figure 14). The tool slides in turn have guides for the cross slides. The cross slides carry the tool holders which can move longitudinally during tool adjustment, and are afterward fastened rigidly to the slide by screws.

The design of the tool holders and slides makes it possible to position the tools accurately with respect to diameter, turning depth and center.

Technical data, S-81A semiautomatic lathe*

Number of spindles	2
Maximum turning diameter, mm	50
Maximum thickness of the part machined, mm	5
Number of spindle speeds	6
Range of spindle speeds, rpm	500-2820
Number of camshaft speeds	30
Range of camshaft speeds, rpm	0.5-7.8
Longitudinal slide travel, mm	30
Transverse slide travel, mm	32
Number of slides	2
Number of tools per toolholder	2
Movement per division of the slide dial, mm	0.01
Number of cams	4+4
Electric motor	0.75 kw, 1000 rpm

The production rate per spindle is an average of 2000 operations per shift.

The kinematic diagram of the machine is given in Figure 15. The electric-motor pulley (1) powers the drive pulley (2) and the spindle pulleys (3) and (4) through a flat belt. Pulley (5), fitted on the driveshaft together with pulley (2), drives the counter shaft pulley (6) by a round belt. The countershaft, in turn, drives gears (10) and (11) on the worm shafts through gears (7), (8) and (9).

Gear (10) is mounted on the right-hand worm shaft together with a claw clutch. The worm wheel (13), in mesh with the single-thread worm (12), is mounted on the camshaft as are the cams (16), (17), (18), and (19). The bell cam (16) controls the slide cross feed. Cam (17), a flat cam, feeds the slide longitudinally. Flat cam (18) shifts the stops for different machining depths. Cam (19), a flat cam, automatically disconnects the machine spindle when the machining cycle is completed. Gear (13) has a pin (20) on its face which automatically disconnects the camshaft through a system of levers connected with the claw clutch when the machining cycle is completed.

The lever arm ratio is 1:1 for cams (16) and (17), and 2:1 for cam (18).

The design and kinematics of the left-hand worm shaft and camshaft are identical with those on the right-hand side. The electric-motor pulley is a change pulley which is one of a set of 6 pulleys. The spindles therefore have 6 speeds. The change gears (7) and (8) give 5 speeds, and the camshafts accordingly have 30 rotation speeds (see Table 1).

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* An improved version of the machine, which is in the planning stage, features a directionally adjustable spindle stop, a higher motor speed, and relief of the spindle of the radial stresses produced by the belt.

The S-81A semiautomatic lathe is used for facing watch parts made of brass, nickel silver, and other nonferrous alloys. Compressed air, taken from the plant supply, is used as a coolant. The lathe is also used for counterboring concentric recesses or for turning outside shoulders. The two spindles are independent so that a part can be machined from both sides or two different parts can be simultaneously machined. If it is required to machine only one side of one part, the second spindle can duplicate the operation of the first spindle. The mechanisms giving the longitudinal and cross slide motions for the approach and retraction of the tools are combined for both slides.

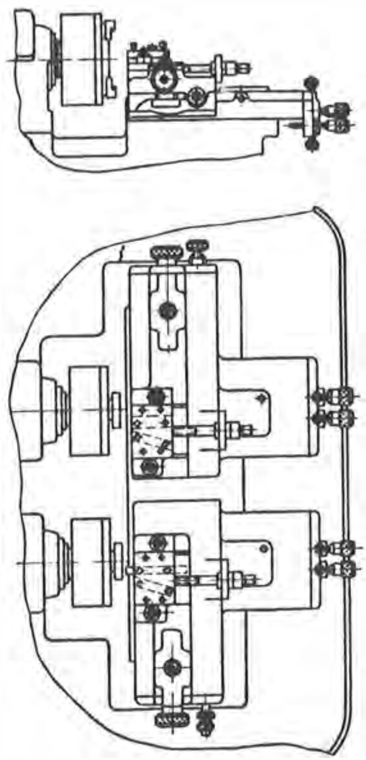

FIGURE 14. Slides of the S-81A machine

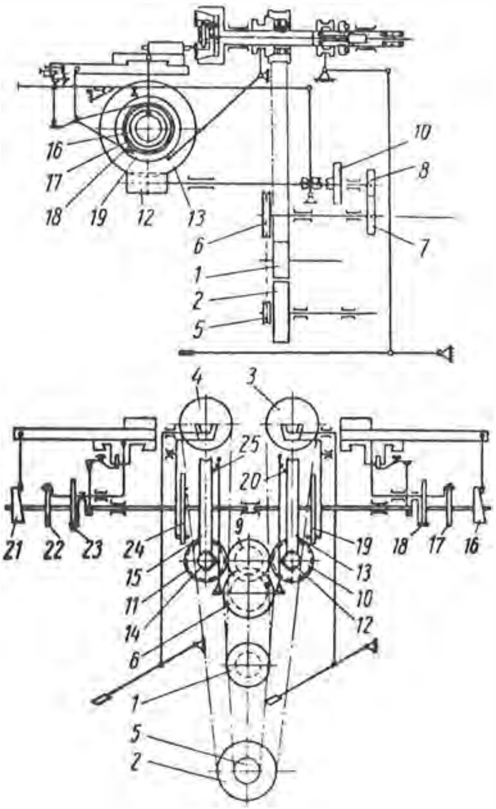

FIGURE 15. Kinematic diagram of the S-81A machine

Parts machined on this lathe have accurate dimensions and a good surface finish, because of the accuracy with which the main assemblies of the machine are built and due to the use of carbide-tipped tools. Depth tolerances of 0.015 mm can be held as well as tolerances of 0.03 mm. The quality of the surface finish corresponds to class 7 – 8.

The cutting conditions for facing and counterboring recesses in plates and cocks (bridges) are determined as a function of the machining diameter, the depth of cut, the required surface finish, and the tool quality.

The cutting speed is calculated on the basis of the maximum machining diameter. The cutting speed corresponding to the maximum spindle speed, $n = 2820$ rpm, and the maximum machining diameter, 50 mm, is:

$$v = \frac{\pi D \cdot n}{1000} = 450 \text{ m/min}.$$

For the "Pobeda" wristwatch plate, having $D = 26$ mm, the cutting speed will be

$$v = \frac{3.14 \cdot 26 \cdot 2820}{1000} \approx 225 \text{ m/min}.$$

It is recommended that the maximum cutting speeds (i.e. those corresponding to $n = 2820$ rpm) be used in machining plates and cocks, as the material from which they are made, LS63-3 leaded brass, has good machinability.

TABLE 1

Camshaft speeds, rpm, of the S-81A machine

Steps of camshafts	Change gears		Spindle rpm					
			500	705	1000	1410	2000	2820
	7	8	Camshaft rpm					
1	48	36	0.51	0.73	1.03	1.46	2.06	2.92
2	44	40	0.76	1.10	1.55	2.20	3.10	4.40
3	40	44	0.945	1.32	1.89	2.64	3.78	5.28
4	36	48	1.14	1.61	2.28	3.22	4.56	6.44
5	28	56	1.38	1.95	2.76	3.90	5.52	7.80

The feed rates are established as a function of the required surface-finish quality and the radius of the tool point. The surface-finish quality increases with the increase in the tool-point radius, but this is accompanied by an increase in the cutting forces which can lead to the deformation of the part.

The surface-finish quality of the tool cutting surfaces must be better by one or two classes than that required of the machined surface.

The feed rates for machining LS63-3 brass are given in Table 2 as a function of the required surface-finish quality and the cutting speed.

The machining time T_m is determined from the formula

$$T_m = \frac{l + l_1 + l_2}{n \cdot s} \text{ min},$$

where T_m = machining (basic) time, min;
l = length of the machine surface, mm;
l_1 = tool approach, mm;
l_2 = tool overtravel, mm;
n = speed, rpm;
s = feed per revolution, mm.

The idle time (corresponding to the idle movements of the machine), calculated according to the following formula, must be added to the basic machining time:

$$T_i = T_m \frac{n_i}{360 - n_i},$$

where n_i = the number of degrees of idle-movement cam angle, according to the operation sheet.

TABLE 2

Feed rates as a function of the required surface-finish quality for facing parts made of LS63-3 brass

v m/min	r_{point} mm	Tools R9; R18			Tools VK8; T15K6		
		Surface-finish class required					
		∇∇6	∇∇∇7	∇∇∇8	∇∇6	∇∇∇7	∇∇∇8
		Feed rates s_0, mm/part rev.					
5–30	0	0.020	0.014	0.009	0.022	0.017	0.012
	0.3	0.021	0.015	0.010	0.023	0.018	0.013
	0.5	0.023	0.017	0.012	0.025	0.020	0.014
	0.8	0.025	0.019	0.014	0.026	0.021	0.016
	1.0	0.027	0.021	0.021	0.028	0.028	0.018
30–70	0	0.022	0.016	0.011	0.024	0.019	0.014
	0.3	0.023	0.017	0.012	0.025	0.020	0.015
	0.5	0.025	0.019	0.014	0.026	0.021	0.016
	0.8	0.027	0.021	0.016	0.028	0.023	0.018
	1.0	0.028	0.023	0.018	0.030	0.025	0.020
Above 70	0	0.023	0.017	0.012	0.029	0.023	0.018
	0.3	0.024	0.018	0.014	0.030	0.024	0.019
	0.5	0.027	0.021	0.016	0.031	0.025	0.020
	0.8	0.029	0.024	0.018	0.032	0.027	0.022

The piece time is the sum $T_m + T_i + T_{aux}$
The auxiliary time is calculated with the aid of special standards*.

Setup Calculation for the S-81A Semiautomatic Lathe

The setup is so calculated as to complete during one camshaft revolution the entire cycle of machining operations for the one station. The cam circumference is divided into 360°, as was the case with the cams for the automatic screw machines.

The cams are mounted on the camshaft in such a way that at the initial moment the rollers, cam toes, and lever pins are positioned at the zero points of the cams.

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* Standards of the Orgmashpribor Institute, 1954.

In the S-81A machine, cams 16, 17, 18, 21, 22, and 23 are exchangeable and the profiles are drawn according to the setup calculation for the part to be worked, while cams 19, 20, 24 and 25 are fixed (see Figure 15).

The idle movements are determined according to Table 3.

TABLE 3

Idle movements for the S-81A lathe

Cam type	Function controlled by the cam-profile section	Cam idling degrees per mm rise or drop
Bell cam (16)	Slide advance to working position and withdrawal therefrom. . . .	1.0-1.5° per mm, but not less than 3° total . . . .
Flat cam (17)	The same	The same . . . .
Flat cam (18)	Stop change	5-6° (total) . . . .
Flat cam (19)	Spindle stoppage	12° (total) overlap . . . .
Pin (20) on gear (13)	Camshaft stoppage	The same . . . .
	Dwell	3° (total) . . . .

The setup calculation begins with the machining plan for the part, which indicates the sequence of all motions executed by the different parts of the machine during the machining cycle. The machining and the idle cam-angles are calculated. This is followed by the establishment of the feed rate per revolution, the calculation of the number of spindle revolutions required for each operation, and the total number required. The overlapping motions are then planned.

Next, are calculated the number of cam degrees per spindle revolution (in machining) and per operation, the number of spindle revolutions necessary for the manufacture of one part, the time required for manufacturing one part, and finally the production rate of the machine per shift. Finally, the cam profiles and the cycle diagrams are drawn.

We will take the setup calculation for the machining of the train bridge of "Pobeda" wristwatches as an example. The bridge is made from LS63-3 brass. The following sequence of operations (and sequence of motions for the working parts of the machine) is established by the operation sheet based on the setup calculation [see operation sheet A]:

1— 2. The spindle is stopped (12° on camshaft), the stop is changed (5°) (see Table 3).

3. Tool advances to working position; travel 16 mm; 20° on cam (17) for this idle movement (Table 3).

4. Dwell of 3° before beginning of machining to prevent the tool plunging during the approach to the bridge.

5. Facing. Tool advances from outer diameter to center. The travel is 12-5.75 + 1 + 0.25 = 7.5 mm, where 12 and 5.75 are the part radii, 1 mm is the tool width, and 0.25 mm the tool overlap for the next operation.

6-9. Tool retracts longitudinally 2.5 mm for the change of plunging stop, and 0.25 mm transversely for the cross-over. The idle-movement cam angle is established according to Table 3. In order to make possible the change of stop (overlapped motion), 10° are fixed for the dwell.

10. After the stop is changed (operation 9), the total advances again and stops 0.2 mm from the part. This safety clearance is necessary to prevent the tool from striking the part, the advance taking place during an idle movement. The idle-movement cam angle is established by Table 3.

11. The tool plunges into the bridge 1.22-0.49 = 0.73 mm. The travel is 0.2 + 0.73 = 0.93 mm.

13. After a dwell of 3° (operation 12) the counterboring of the recess is effected, leaving a wall thickness of $0.49^{-0.02}$ mm. The travel is 6 mm. The tool overtravel, necessary to ensure that the entire surface is faced, is 0.25 mm.

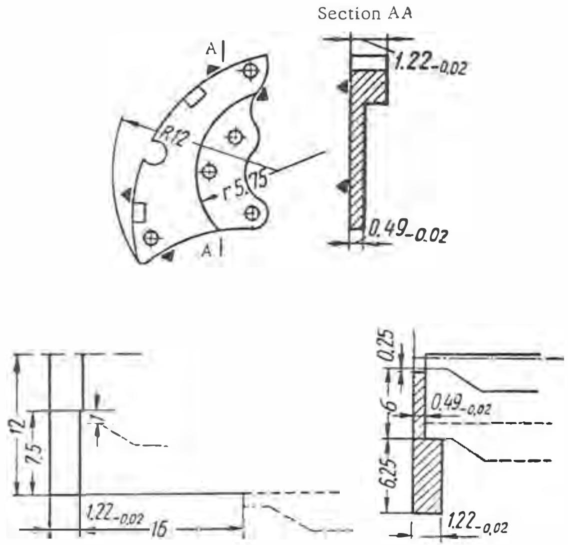
14. Dwell — 3°.

15— 16. Tool retracts to neutral position longitudinally and transversely simultaneously. The idle-movement cam angle is established according to Table 3.

Operation sheet A

Operation sheet for the semiautomatic S-81A lathe

Part name	Part No.	Cutting speed	215 m/min
Train bridge	K-26-3	Spindle speed	2820 rpm
Material	LS63-3 brass	Production rate per spindle	4.40 pieces/min



Number	Sequence of operations	Tool travel, mm	Cam number	Lever arm ratio	Feed, mm per spindle revolution	Number of working revolutions	Number of cam degrees: machining	Number of cam degrees: idle movement	Sum of cam degrees: from	Sum of cam degrees: to
1	Spindle stoppage . . .	-	19	-	-	-	-	12	0	12
2	Stop change	-	18	2:1	-	-	-	(5)	5	10
3	Tool approach, longitudinal	16	17	1:1	-	-	-	20	12	32
4	Dwell	-	-	-	-	-	-	3	32	35
5	Finish face dimension 1.22-0.02	7.5	16	1:1	0.025	290	145	-	35	180
6	Tool retraction, longitudinal	2.5	17	1:1	-	-	-	5	180	185
7	Dwell	-	17	1:1	-	-	-	10	185	195
8	Tool retraction, transverse	0.25	16	1:1	-	-	-	(5)	186	191
9	Stop change	-	18	2:1	-	-	-	(5)	187	192
10	Tool approach, longitudinal	2.3	17	-	-	-	-	5	195	200
11	Tool plunge	0.93	17	1:1	0.013	70	33	-	200	233
12	Dwell	-	17	-	-	-	-	3	233	236
13	Face dimension 0.49-0.02	6	16	1:1	0.03	190	97	-	236	333
29	Dwell	-	-	-	-	-	-	3	333	336
15	Tool retraction, longitudinal	16.73	17	1:1	-	-	-	24	336	360
16	Tool retraction, transversal.	13.25	16	1:1	-	-	-	(15)	345	360
						550	275°	85°	-	360°

After the operations and idle movements, the tool travels and the cam angles corresponding to them, have been calculated, the feed rates for operations 5 and 13 are established. According to Table 2, the feed rate per spindle revolution will be 0.025 mm for producing the dimension $1.22^{-0.02}$ mm, and 0.03 mm for the dimension $0.49^{-0.02}$ mm. The 1.22 mm face is a mounting surface for the watch bridge, and its surface-finish quality must therefore be better than that of the 0.49 mm surface. The feed selected for the first face is accordingly lower.

A minimum feed rate of 0.013 mm is selected for plunging in operation 11.

The number of spindle revolutions per operation is calculated by dividing the travel by the feed rate. A rounding-off of the values obtained is allowable in both directions.

A summation of the number of machining spindle revolutions, and of the number of idle-movement cam degrees is now carried out. According to the operation sheet, there are 85° of idle movements, which constitute 24% of the total cam angle, and 360°-85° = 275° of machining cam angle, which are 76% of the cycle total.

The total number of machining spindle revolutions is 550, and therefore the cam angle corresponding to one spindle revolution is 275°/550 = 0.5°.

Now, the number of cam degrees corresponding to each operation is introduced into the operation sheet next to the number of revolutions. The number of degrees is calculated by multiplying the number of revolutions by 0.5.

The sum of the cam degrees for the three machining operations must be 275°.

The number of spindle revolutions necessary for the manufacture of one part is determined from the relation

$$x:550 = 360:275; \quad x = \frac{360\cdot550}{275} = 720 \text{ revolutions.}$$

The production rate of the machine is calculated by dividing the selected spindle speed by the number of revolutions necessary for the manufacture of one piece.

Bridges are machined using the maximum spindle speed of 2820 rpm.

The production rate will therefore be

$$A = \frac{2820}{720} = 4 \text{ pieces/min.}$$

The machining time will be $T_m = \frac{60}{4} = 15$ sec, and the cutting speed $v = \frac{3\cdot14\cdot2820\cdot24}{100} = 215$ m/min.

The nearest camshaft speed is selected from Table 1: $n_{cam} = 4.4$ rpm. The actual production rate will then be 4.4 pieces/minute, and 480·4.4 = 2110 pieces/shift.

$$T_m = \frac{60}{4.4} = 13.6 \text{ sec.}$$

The cycle diagrams for cams (16), (17), and (18) are given in Figure 16. The cam rise and drop profiles are drawn by the same methods as were used for cams of automatic screw machines.

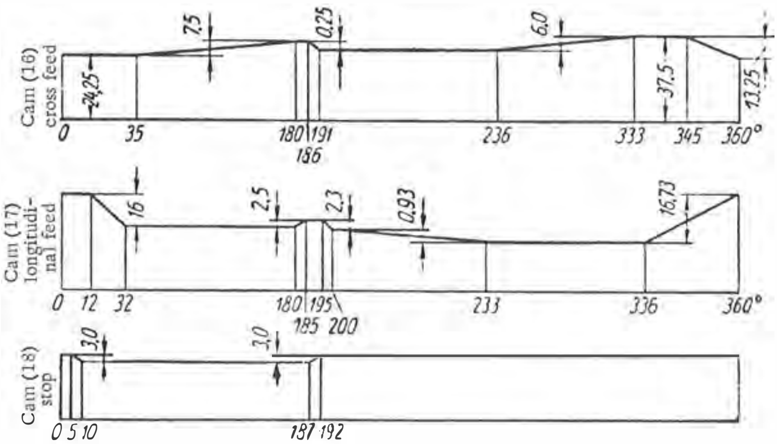


FIGURE 16. Cycle diagrams for cams (16), (17), and (18) on the S-81 machine (machining of the train bridge)

Concentric recesses are also bored on the S-57M machine whose design is similar to that of the S-81A machine. The two machines differ in the method of chucking the work. In the S-81A machine the part is gripped on its periphery by a collet chuck, while in the S-57M machine it is gripped by fingers of a jaw chuck from the machined side. Therefore, only on the S-81A machine can the whole face surface of a part be machined.

The S-57M machine gives a more accurate boring depth, the part fitting more closely against the bearing surface.

Both types of semiautomatic machines have a high production rate and are characterized by easy servicing and simple adjustment.

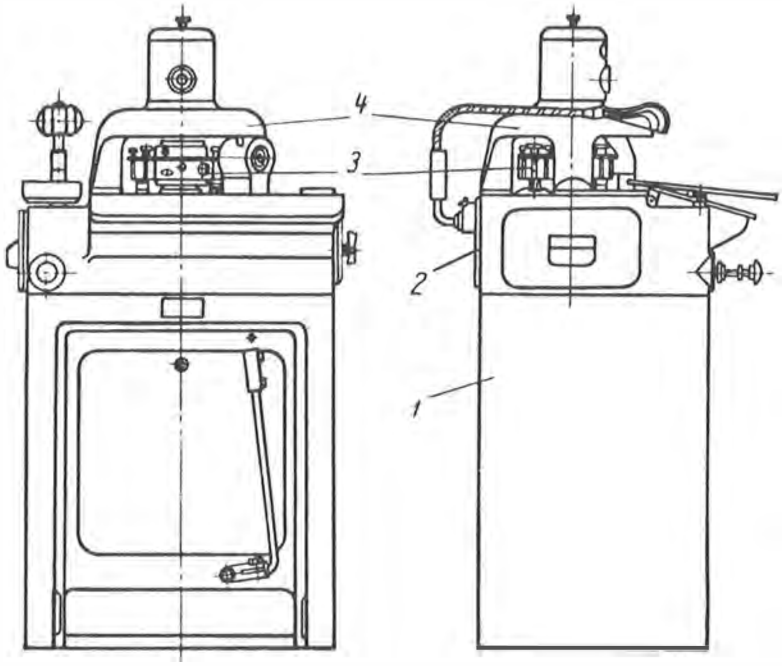


FIGURE 17. General view of the S-188 rotary shaping machine

The S-188 rotary shaping machine (Figure 17) consists of the base (1), the bed (2), the rotary tool head (3), and a chucking fixture. The base has a starting pedal on its front face. The working parts of the machine are mounted inside the bed (2): the drive, the cams controlling the chucking and ejection of the part, the chucking fixture, and the lower end of the spindle. The upper end of the spindle is fastened in housing (4).

The rotary tool head (2) (Figure 18), on whose circumference are mounted five tools (3), is fastened on the machine spindle (1). Cams (4) and (5) control the chucking and ejection of the part. The spindle revolves at 70 rpm, corresponding to a cutting speed of 30 m/min at the mean diameter of the rotary head. One part is machined per head revolution, and the machining (basic) time is therefore about 1 sec; the auxiliary time is 1 to 2 sec.

The part is positioned manually in a fixture on table (6), and ejected automatically by rotating lever (7). The part is held fixed during machining.

The head is stopped by cam (8). The chips are blown away by air, fed through a cam-controlled valve.

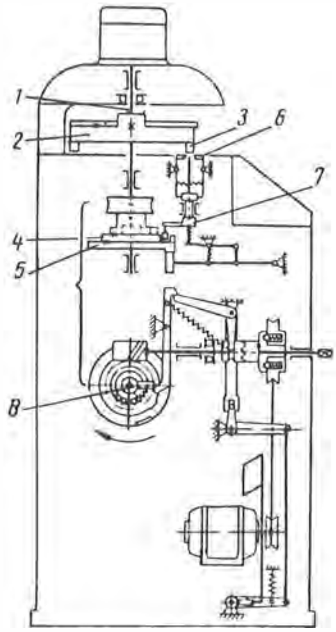


FIGURE 18. Kinematic diagram of the S-188 rotary shaping machine

The part to be machined is pressed by two jaws (1) (Figure 19) against stop (2) and platen (3). The chucking jaws are fastened to levers (4), which are actuated by cam (5) when lever (7) is rotated.

Ejection is controlled by cam (5) (Figure 18) through plunger (6).

A sloped chute for removing the parts is attached to the chucking fixture.

The cycle diagrams for the machine cams are given in Figure 20. Idle movements constitute 13% of the part time.

The material allowance, 0.2 mm per side, is uniformly distributed among the five tools. The machine produces a class 9 or 10 surface-finish quality, while the parallelness and flatness are between 0.005 and 0.010 mm and depend to a considerable extent on the positioning and sharpening of the tools. The head was so designed that the tool position can be adjusted both in the vertical direction and in the plane, the width of the tool bit being 35 mm.

Rotary shaping is more productive than facing, and the S-188 machines are accordingly being used to an increasing extent in watch production of late.

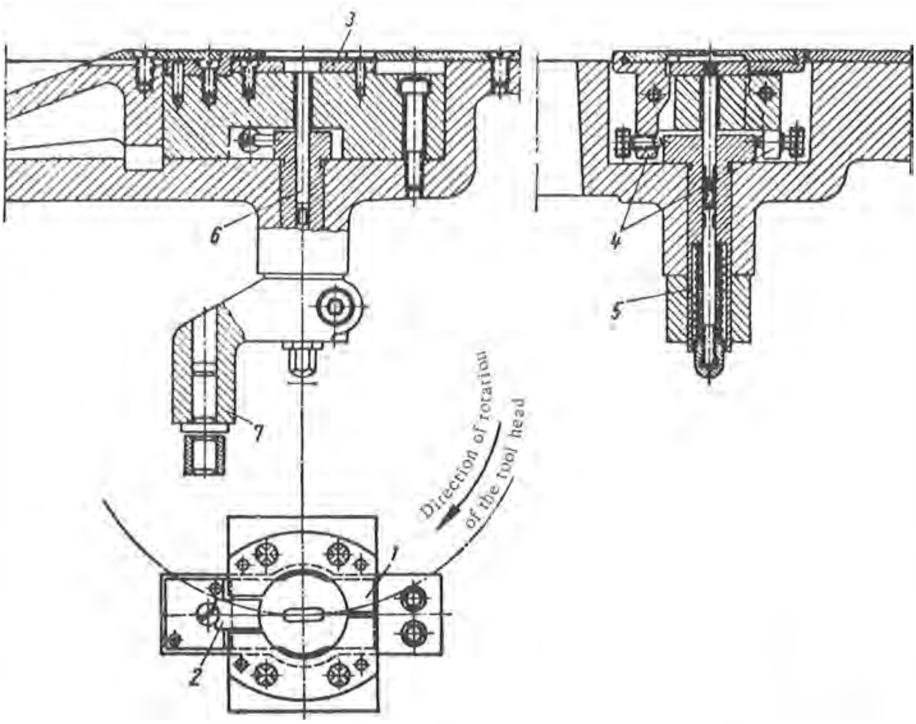


FIGURE 19. Chucking fixture for the S-188 rotary shaping machine

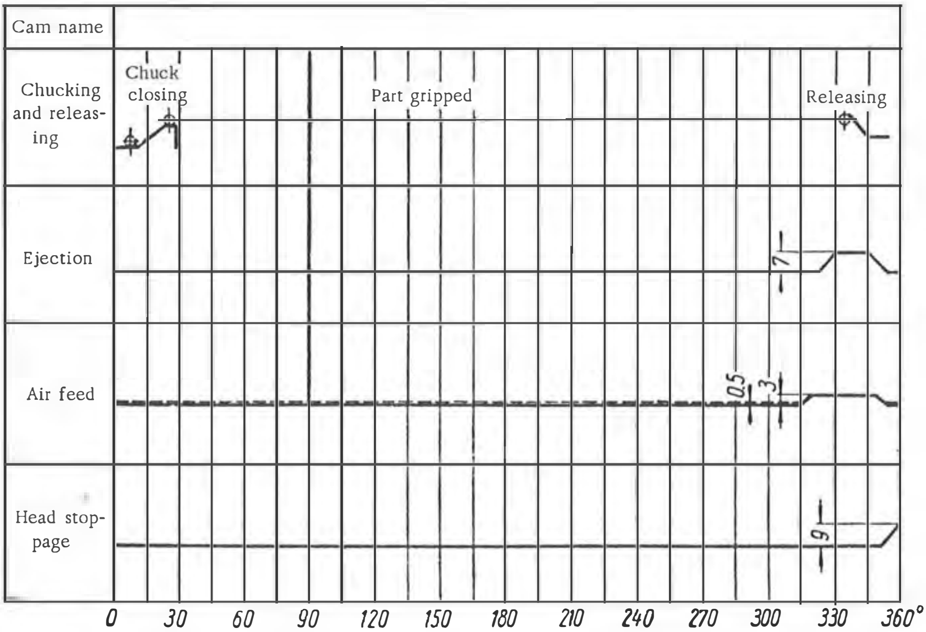


FIGURE 20. Cycle diagram of the S-188 machine

Technical data of the S-188 machine

Maximum diameter of the machined part, mm	28
Thickness of the machined part, mm:	
maximum	6
minimum	1
Maximum material allowance per side, mm	0.2
Tool-head speed, rpm	70
Cutting speed on the mean circumference, m/min	30
Electric motor	0.6 kw, 1500 rpm
Production rate, parts per shift	9,000–10,000

THE MILLING OF RECESSES AND PROJECTIONS

In small-series production tracer-controlled universal milling machines of the 678-M type, and duplicating machines with pantograph mechanisms of the 6461 and 6463 types, are used for reproducing complex contours. Both types of machine use an accurately contoured template. The scale is 1:1 for the universal machine, and 10:1 for pantograph machines. These machines are not, however, very productive. In mass production more productive machines, such as the S-50 semiautomatic milling machine and the S-187 two-spindle semiautomatic milling machine, are used.

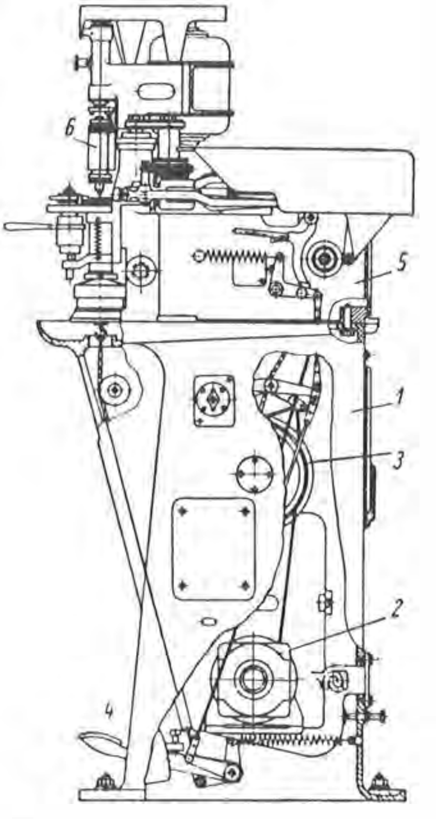


FIGURE 21. S-50 semiautomatic milling machine

The S-50 semiautomatic milling machine (Figure 21) serves for milling complex recesses and projections of various depths in plates and cocks, and for engraving inscriptions and drawings on flat parts. The machine permits both continuous and intermittent milling. In the latter case several recesses of different contour and depth can be milled in one station.

Recesses of complex configuration are milled by the simultaneous motion of the cutter spindle and the work table in the horizontal plane. Any required configuration can be obtained by the combination of suitable angular displacements of the spindle and the table in the horizontal plane. The table is lifted and lowered by a cam, thus producing recesses of nonuniform depth. The machine consists of four main units: the base, the camshaft housing, the spindle head, and the work table.

The base (1) is of cast iron and in it are mounted the electric motor (2) powering the camshaft, the planetary reduction gear (3), and the starting pedal (4). The camshaft housing (5) is mounted on the base. The following working assemblies of the machine are mounted on and inside the camshaft housing body: the worm shaft, the camshaft, the cutter and table levers, and the table-lifting lever. The spindle head (6) is a cylindrical body inside which the cutter spindle revolves in four bearings (see technical data).

The machine is equipped with two electric motors. One motor (Figure 22) drives the camshaft and is mounted inside the bed. The second motor drives the cutter spindle and is mounted in the body of the head on a special bracket. Pulley (1, 2, 3) on the first motor drives the reduction-gear pulley (4, 5, 6) through a round belt. A planetary transmission, consisting of the four gears (13, 14, 15, 16), with a transmission ratio 1:3.87, is mounted inside pulley (4, 5, 6). Two brake pulleys (19, 20) are mounted on the reduction-gear shafts.

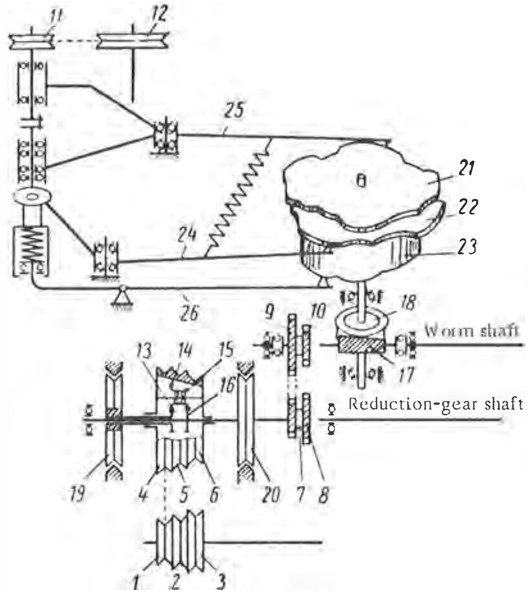


FIGURE 22. Kinematic diagram of the S-50 machine

The planetary gear, intended to reduce the speed of rotation of the reduction-gear shaft, consists of the two sun gears, (13) with 31 teeth and (16) with 36 teeth, a pinion and two brake pulleys.

The sun gear (13) and the brake pulley (19) are rigidly connected to each other, but revolve freely on the reduction-gear shaft. A two-step sprocket wheel (7 – 8) is rigidly connected with the sun gear (16) and the brake (20).

The three-step pulley (4, 5, 6) is the planet-pinion carrier. The pinion in turn consists of two gears, (14) with 36 teeth and (15) with 31 teeth.

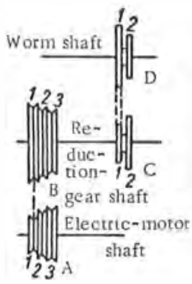
The reduction-gear shaft drives the worm shaft through the sprocket wheels (7), (8), (9), (10) and a roller chain. The worm shaft drives the camshaft through the worm (17) (1 tooth) and wheel (18) (45 teeth). Six different camshaft speeds can be achieved using the three-step pulley (4, 5, 6) and the two-step sprocket (7-8). Three cams are fitted on the vertical camshaft. The upper flat cam (21) controls the angular displacement of the cutter spindle. The middle cam (22), also a flat cam, controls the angular displacement of the table. The lower cam (23), a bell cam, controls the vertical displacement of the table when milling to various depths.

The lower cam (23) and cam (22) are one unit. The table lever (24) is fastened to the front part of the machine head. Its long arm has a prismatic follower at its extremity, which is pressed against cam (22) by a spring. The short arm supports the work table. The work is mounted on a special pin plate on the table and is pressed against it by a cleat by means of a special handle.

Lever (25), which supports the cutter spindle, is mounted on the body of the machine head. Its long arm is equal in length to the long arm of the table lever (24) and on its short arm are mounted the cutter spindle and the bracket with the electric motor. The motor drives the spindle through pulleys (11) and (12) and a round belt. Pulley (11) drives the spindle through a clutch in order to relieve the spindle of the bending moment from the belt.

TABLE 4

Duration of cycles of the S-50 machine

Belt position	Pulleys and sprocket wheels				Camshaft period (time/cycle), sec	Camshaft rpm	Number of spindle revolutions per camshaft revolution
	A A	B B	C C	D D			
	1	1	1	1	95.6	0.63	8300
	2	2	1	1	52	1.15	4500
	1	1	2	2	40	1.5	3400
	3	3	1	1	33.5	1.8	2900
	2	2	2	2	22	2.76	1900
	3	3	2	2	14	4.3	1170

Lever (26) is mounted inside the body of the head. One of its arms has at its extremity a roller follower in contact with the bell cam (23). The other arm is in contact with a disk on the table spindle. The machine has adjusting fixtures for the correct positioning of work and cutter. Data on the machine-cycle duration as a function of the position of the belt and chain on the pulleys and sprocket wheels are given in Table 4.

The camshaft speed remains constant throughout the cycle.

The machine is started by a rotary switch, which starts both motors simultaneously but does not start the camshaft. The parts are positioned and removed manually.

The camshaft is started by pressing the right-hand pedal; this frees pulley (20) and brakes pulley (19).

The machine is switched off automatically after one camshaft revolution. The camshaft can be rotated manually for machine adjustment.

Technical data, S-50 semiautomatic milling machine

Maximum milling diameter or field, mm	40
Maximum milling depth, mm	3
Arm ratio of levers (24) and (25)	90:276
Arm ratio of lever (26)	1:4
Angular rotation of cutter-spindle lever (25), degrees	From −6.5 to +14.5
Angular rotation of table lever (24), degrees	From −6.5 to +14.5
Design diameter of the cams, mm	202
Maximum cam diameter, mm	320
Minimum cam diameter, mm	150
Height accuracy, mm	0.01
Contour accuracy, mm	0.02
Surface-finish-quality class, GOST 2789-51	8
Production rate, operations per shift	400-2000
Cutter-spindle motor	0.35 kw, 3000 rpm
Camshaft motor	0.25 kw, 1500 rpm

Setup Calculation for the S-50 Semiautomatic Machine

The cams for the S-50 semiautomatic machine are calculated in the following way.

1. The part to be machine (Figure 23) is drawn to a scale of 20:1. The sequence of contour-machining operations is marked on the drawing, and the cutter center pitch is drawn at a distance from the contour equal to half the cutter diameter. The length of the cutter path in machining and the length of the idle movements are calculated separately. For large idle movements it is suggested to assign 4 – 5 mm rise and 6 – 7 mm drop per cam degree. The total cam angle required for machining and that required for idle movements are then determined.

The length of path per degree of camshaft rotation is then calculated for the machining and idle portions, and sectors corresponding to 1 camshaft degree are marked and numbered from 0 to 360. Sectors of the same depths are milled consecutively and continuously.

2. A sheet of tracing paper with a degree network (Figure 24) drawn to the same scale as the part drawing (20:1) is superposed over the part drawing. The network must be so superposed that the contour to be milled is near the maximum radius, as this will make the cam curves less steep. The initial position of the cutter must be outside the zone where the part is located in order to facilitate positioning and removal, but near the first plunge point and the exit point so as not to require too much rise and drop on the cams.

3. After the tracing paper has been fastened on the drawing, the angles of rotation of both levers for each point on the cutter path are visually determined. The values of the angles of rotation $\Delta\beta$ and $\Delta\gamma$ (Figure 25) are translated by means of a special table (Appendix 4) into increments ΔR of the cam radii, which are written into the cam-figuring sheet.

The radial increment ΔR is measured from the design diameter, 202 mm, (R = 101 mm), with positive sign when the lever is lifted, and with negative sign when it is lowered.

4. The maximum milling depth is determined from the part drawing. The maximum depth corresponds to the maximum height of the cylindrical cam to a scale of 4:1. The maximum height on the cam according to the design data for the machine must not exceed 18 mm, and therefore the milling depth cannot exceed $\frac{18}{4}$ = 4.5 mm. The cam angle of rise (relative to the horizontal line) must not be greater than 50°, and the angle of drop must not exceed 75°. The angles are measured from the zero line of the table cam.

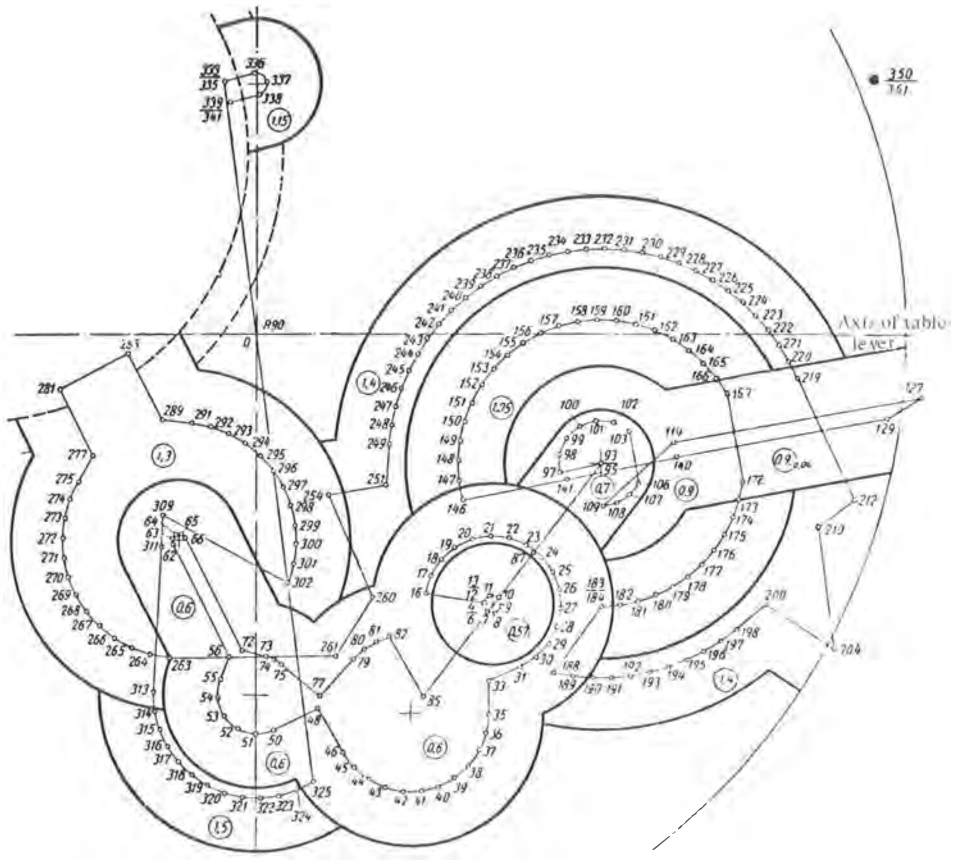


FIGURE 23. Cutter path for machining recesses in the plate of "Molniya" pocket watches

The zero line of cam (23) is shifted by 177° relative to the zero line of cam (22).

Plotting the degree network. The degree network should be drawn as accurately as possible. The working angle of rotation for table and cutter levers lies within the limits of between +14°30' and 6°30'. The origin of coordinates on the network corresponds to the zero position of the levers when the cutter center coincides with the table center, and the cam followers lie on the circumference of the cams at the design diameter of 202 mm. The origin of coordinates on the network lies at the intersection of the two arcs R = 90, which correspond to the paths of the cutter and table centers. Additional arcs, or radii R = 70, 75, 80, 85, 90, 95, 100 from the center of rotation of the table lever have been drawn for convenience.

Determination of the number of idle-movement cam degrees. As a rule, the largest idle movement is the advance of the cutter from its initial position to the beginning of machining, or the withdrawal of the cutter to the initial position after the termination of machining.

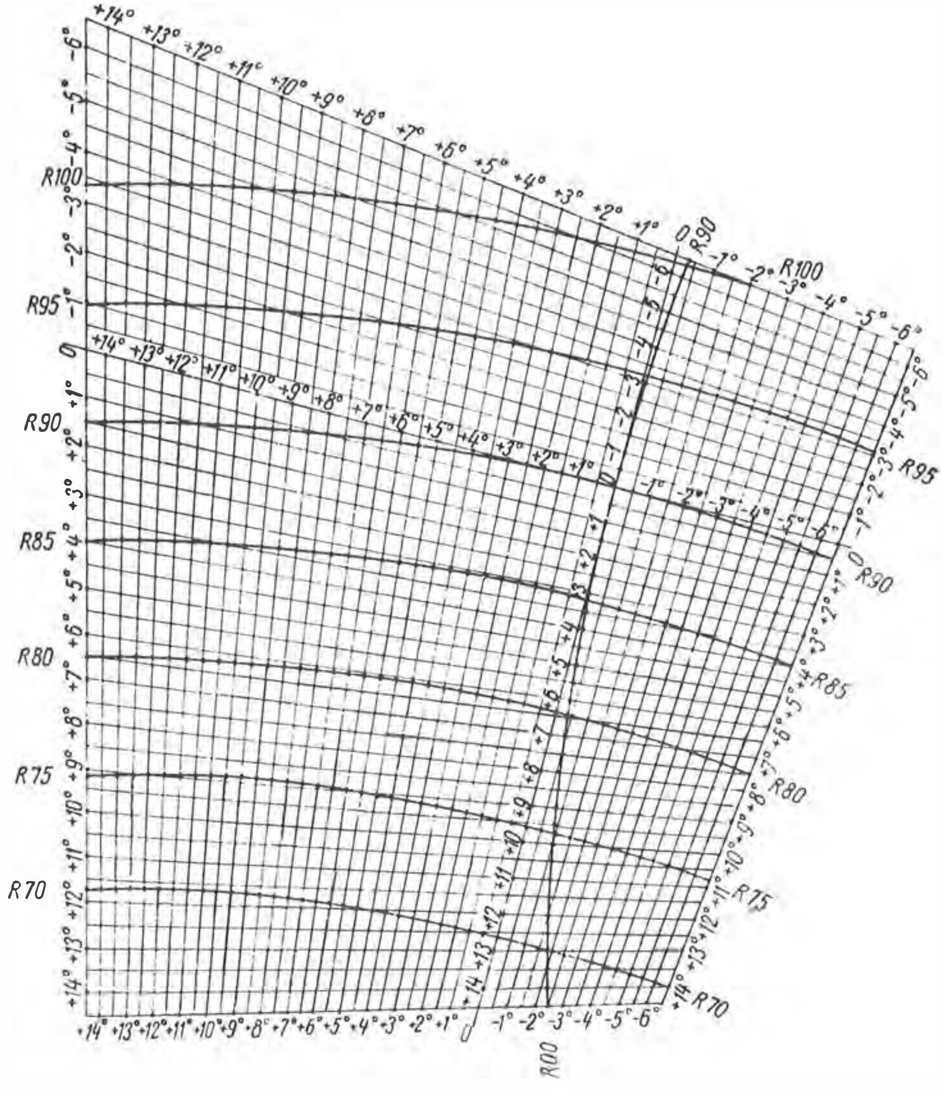


FIGURE 24. Degree network for figuring the cams of the S-50 machine

The order of determination of the cam-rotation angles is as follows. First, the angles of the two levers in the initial position relative to the origin of coordinates are determined on the network. The angles obtained are converted (using the table (Appendix 4)) into the radial increments ΔR. The angular positions of the two levers for the plunging point B are then determined (Figure 25), and their values similarly converted into radial increments ΔR. The algebraic difference between the increments represents the value of the rise for each cam. The cutter advance results from the two motions (cutter lever and table lever), and the cam angle will be the same for both cams.

The cam angles corresponding to the other idle movements are determined in the same way.

Dwells of 1 to 2° must be scheduled at the end of each rise or drop in order to ensure a smooth transition. A dwell of 3 to 6° is scheduled after the cutter retracts to its initial position for the automatic switching off of the machine.

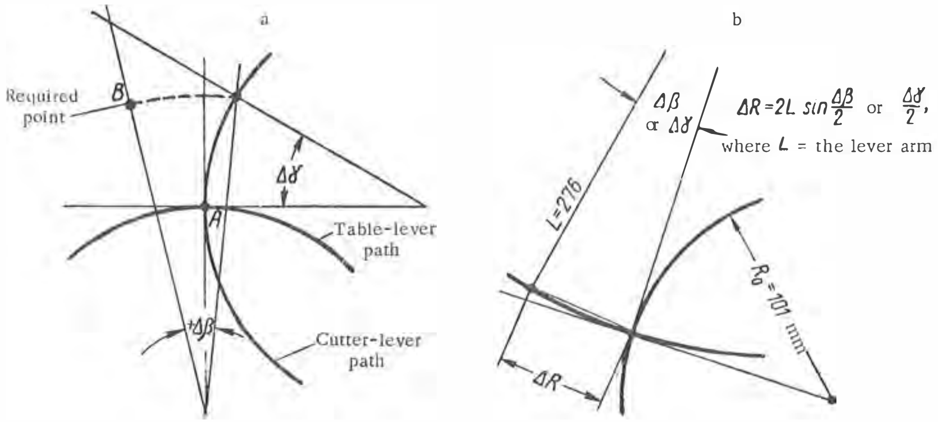


FIGURE 25. Setup calculation for the S-50 machine:

a – angles of rotation of the lever; b – increment of the cam radius, ΔR.

Determination of the number of cam degrees for actual machining. The number of cam degrees per path point (or the path length in mm per cam degree) is determined by subtracting the total number of idle-movement degrees from 360° and dividing the result by the length of the actual machining path of the cutter. The points are numbered in accordance with the corresponding cam angles. In splitting the machining path into sectors, the following conditions must be observed: a whole number of degrees is apportioned to each sector drawn according to the same law (arc, straight line). Each arc-shaped sector is divided into a number of parts equal to the number of degrees apportioned to it, and the points of division are numbered accordingly. For straight sectors, only the initial and final points are numbered. If arcs of small radius, corresponding to a segment of 1 to 2°, are encountered in the cutter path, it is necessary to deviate from the accepted design values and to add to the number of cam degrees on this arc in order to obtain the proper geometry for the contour to be milled (see points 62 to 66 in Figure 23).

The design number of degrees can be correspondingly reduced in straight sectors (see points 85-87).

In plunging and lifting, the cutter does not move along the contour, while the camshaft continues to revolve. These points are accordingly numbered by two numbers (point $\frac{4}{6}\ \frac{13}{12}$ in Figure 23).

The values of the angles for each point are converted according to the table (Appendix 4) into increments ΔR. The tabular values are calculated according to the formula

$$\Delta R = 2l \cdot \sin\frac{\Delta\beta}{2},$$

where l = the lever arm.

The curves on the cams are Archimedean spirals.

Analysis of the accuracy of the method of cam figuring. Errors are inevitable in the graphical plotting of the network and in the part drawing. These errors will be transferred to the product together with the errors in cam manufacture and the errors in the machine operation. The error in graphical plotting consists of: the error in graphically plotting the cutter path to a scale of 20:1 (Δ_1 = 0.02 mm), the error in drawing the degree network (Δ_2 = 0.02 mm), a measuring error of 0°1' on the network or correspondingly on the part (Δ_3 = 0.026 mm), and the error resulting from the conversion of the angle to ΔR according to the table in Appendix 4 (Δ_4 = 0.003 mm).

The maximum total error of the graphical method is Σ_Δ = 0.07 mm. The graphical plotting and the measurements must accordingly be done very carefully.

Determination of the duration of the machining cycle. Duration of one machining cycle is determined by the formula

$$T_{\text{sec}} = \frac{360^\circ}{\alpha^\circ} T_{\text{op}},$$

where T_{op} = the time during which the cutter is in operation;
α° = the sum of idle-movement cam degrees;

with

$$T_{\text{op}} = \frac{60 \cdot s}{m \cdot b \cdot n},$$

where s = the length of the cutter machining path (according to the drawing);
m = the scale 20:1;
b = the feed per cutter revolution, (0.03 – 0.04 mm);
n = the cutter rpm (5200), and

$$T_{\text{sec}} = \frac{360^\circ \cdot 60 \cdot s}{\alpha^\circ \cdot m \cdot b \cdot n}.$$

The production rate of the machine is $A = \frac{60}{T_{\text{sec}}} = n$ pieces/minute.

Cam-figuring example for the milling of plates

The initial position of the cutter, in machining the "Molniya" brand pocket-watch plate corresponds to points 350 — 351 (Figure 23). The cutter is rapidly advanced through the sector 351-4, and the angle of rotation of the cam is 13°.

The cutter plunges in sector 4 — 6 to the 0.57 mm plane (0.57 mm is the thickness), and then follows the anticlockwise circuit 6 — 12. From point 12 to point 13 the cutter moves to the 0.6 mm plane (the table drops 0.03 mm). At this new depth it moves along a straight line to point 16.

The cutter then describes a circular arc to 31°. Sectors 31 — 33 — 35 are straight lines and serve for by-passing the point of contact between the two arcs. The sectors 35 — 46 — 48 — 50 — 55 — 56 — 62 — 66 — 72 — 73 — 75 — 77 — 79 — 82 — 85 are milled at the same 0.6 mm depth. The intervals between the points in sectors 6 — 12, 62 — 66 and 73 — 75 have been reduced in order to obtain a more accurate contour. The cutter is rapidly advanced along a straight line for the idle movement in the sector 85 — 87, with a simultaneous change in the milling depth to the 0.7 mm plane. This plane is machined in sector 87 — 93 in one cutter pass (the cutter diameter is equal to the slot width). The milling depth changes from 0.7 to 0.9 mm in sector 93 — 95.

The 0.9 mm plane is machined on sectors 95 — 97 — 103 — 106 — 109 — 114 — 127 — 129 — 140. The cutter is rapidly advanced in sector 140 — 141 and the depth is simultaneously changed for the 1.05 mm plane. The rapid advances on sectors 85 — 87 and 140 — 141 are easily made, as no metal is removed in these places. The 1.05 mm plane is machined on sectors 141 — 146 — 167 — 172 — 183. The milling depth is changed on sector 183 — 184 to 1.4 mm. The plate is milled at this depth on sectors 184 — 188 — 198 — 200 — 204 — 210 — 212 — 219 — 249 — 254 — 260.

The cutter is rapidly advanced over sectors 260 — 261 — 263, passing simultaneously to the 1.3 mm plane, after which it continues on sectors 263 — 275 — 277 — 281 — 285 — 289 — 291 — 302 — 309 — 311. Sector 313 — 325 is machined on the 1.5 mm plane, after which the cutter leaves the plate and moves (above the surface of the component) to point 333. It plunges on sector 333 — 335 to the 1.15 mm plane and continues along sectors 335 — 336 — 338 — 339. On sector 339 — 341 of the cam the cutter again leaves the plate and returns on sectors 341 — 350 to its initial position. The time taken by one cycle is 52 sec. The camshaft revolves at speed No. 2. The rotation angles for the table lever and the cutter lever are determined from the path diagram by superposing over the component's drawing the degree grid, and the values obtained are introduced into the setup sheet for each cam. The profiles of cams (21), (22), and (23) are shown in Figures 26 and 27, and the calculation tables are given.

Calculation of the bell cam (23). The maximum milling depth (0.57 mm in Figure 23) corresponds to 16 mm cam height. The rise or drop on the cam corresponds to a rise or drop of the work table to a scale 4:1. A change in the milling depth from 0.57 to 0.6 mm thus corresponds to a drop of $(0.6 - 0.57) \times 4 = 0.12$ on the cam. The zero point of the bell cam (23) is shifted by $360 - 177° = 183°$ relative to the zero point of cam (22).

Let us examine the transition from depth 0.57 mm to depth 0.6 mm. This corresponds to points 12° — 13° on the cutter path. The transition must begin not earlier than 12° and end not later than 13°. The corresponding angle on the bell cam is 196° according to the following calculation: the beginning of the transition is taken as $13 + 183° = 196°$, i.e. with a delay of 1°, taken as allowance for cam adjustment.

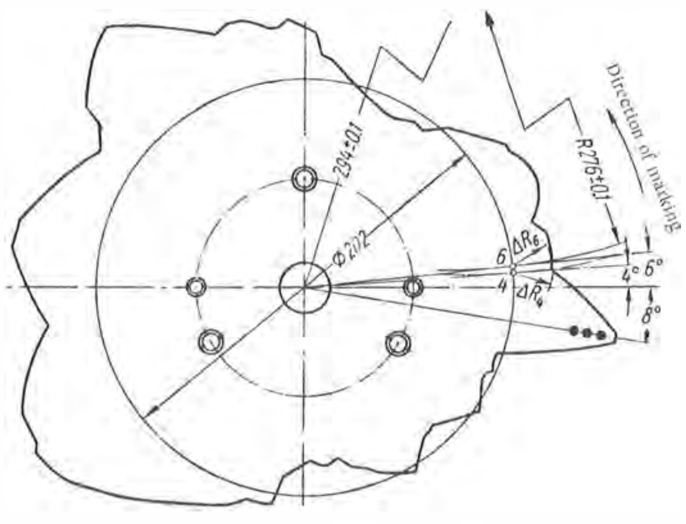


FIGURE 26. Profile of cam (21)

Calculation table A: cutter cam

No.	ΔR	No.	ΔR	No.	ΔR	No.	ΔR	No.	ΔR
4	+18.63	55	− 4.74	154	+21.68	221	+45.31	273	−17.27
6	+18.63	56	− 3.86	155	+22.96	222	+44.35	274	−15.34
7	+19.11	62	− 7.87	156	+24.56	223	+43.23	275	−14.94
8	+19.51	63	− 7.95	157	+26.17	224	+42.03	277	−14.46
9	+20.07	64	− 7.63	158	+27.69	225	+40.67	281	−17.27
10	+19.91	65	− 7.15	159	+29.37	226	+39.47	285	−11.25
11	+19.11	66	− 6.83	160	+31.14	227	+37.95	289	− 8.27
12	+18.63	72	− 2.57	161	+32.82	228	+36.51	291	− 5.78
13	+18.63	73	− 0.64	162	+34.42	229	+34.91	292	− 4.10
16	+13.66	74	0.00	163	+36.11	230	+33.46	293	− 2.57
17	+14.22	75	+ 0.64	164	+37.39	231	+31.70	294	− 1.21
18	+15.10	77	+ 3.62	165	+38.67	232	+30.10	295	+ 0.08
19	+16.47	79	+ 6.83	166	+39.71	233	+28.33	296	+ 1.12
20	+17.91	80	+ 7.79	167	+40.59	234	+26.89	297	+ 1.93
21	+19.51	81	+ 8.92	172	+41.39	235	+25.20	298	+ 2.49
22	+21.12	82	+10.04	173	+40.91	236	+23.60	299	+ 2.73
23	+22.64	85	+12.53	174	+40.51	237	+22.24	300	+ 2.73
24	+23.76	87	+23.12	175	+39.71	238	+20.72	301	+ 2.49
25	+24.64	93	+29.37	176	+38.75	239	+19.43	302	+ 1.77
26	+25.04	96	+29.37	177	+37.63	240	+18.07	309	− 8.68
27	+25.04	97	+25.77	178	+36.27	241	+16.87	311	− 8.92
28	+24.64	98	+25.85	179	+34.91	242	+15.83	313	−10.68
29	+23.84	99	+26.65	180	+33.38	243	+14.70	314	−10.76
30	+22.64	100	+27.77	181	+31.78	244	+13.82	315	−10.52
31	+21.12	101	+29.21	182	+30.18	245	+13.17	316	−10.04
33	+18.31	102	+30.74	183	+28.57	246	+12.45	317	− 9.24
35	+17.91	103	+32.02	184	+28.57	247	+11.97	318	− 8.27
36	+17.43	106	+32.50	188	+24.00	248	+11.49	319	− 7.07
37	+16.71	107	+31.70	189	+25.61	249	+11.25	320	− 5.62
38	+15.67	108	+30.58	190	+27.21	251	+10.68	321	− 4.18
39	+14.38	109	+29.29	191	+28.89	254	+ 5.70	322	− 2.57
40	+12.85	114	+35.87	192	+30.58	260	+ 9.00	323	− 0.096
41	+11.33	127	+57.70	193	+32.26	261	+ 5.30	324	+ 0.64
42	+ 9.80	129	+54.66	194	+33.86	263	− 9.00	325	+ 2.17
43	+ 8.19	140	+35.95	195	+35.47	264	−10.60	333	− 3.70
44	+ 6.91	141	+26.33	196	+37.07	265	−12.13	335	− 3.70
45	+ 5.78	146	+17.35	197	+38.67	266	−13.58	336	− 1.12
46	+ 4.98	147	+17.03	198	+40.11	267	−14.78	337	0.00
48	+ 3.37	148	+17.11	200	+42.85	268	−15.91	338	− 0.64
50	− 0.72	149	+17.43	204	+48.51	269	−16.63	339	− 3.05
51	− 2.25	150	+17.91	210	+48.03	270	−17.27	341	− 3.05
52	− 3.78	151	+18.55	212	+51.14	271	−17.43	350	+51.30
53	− 4.82	152	+19.43	219	+46.91	272	−17.51	351	+51.30
54	− 5.22	153	+20.48	220	+46.91				

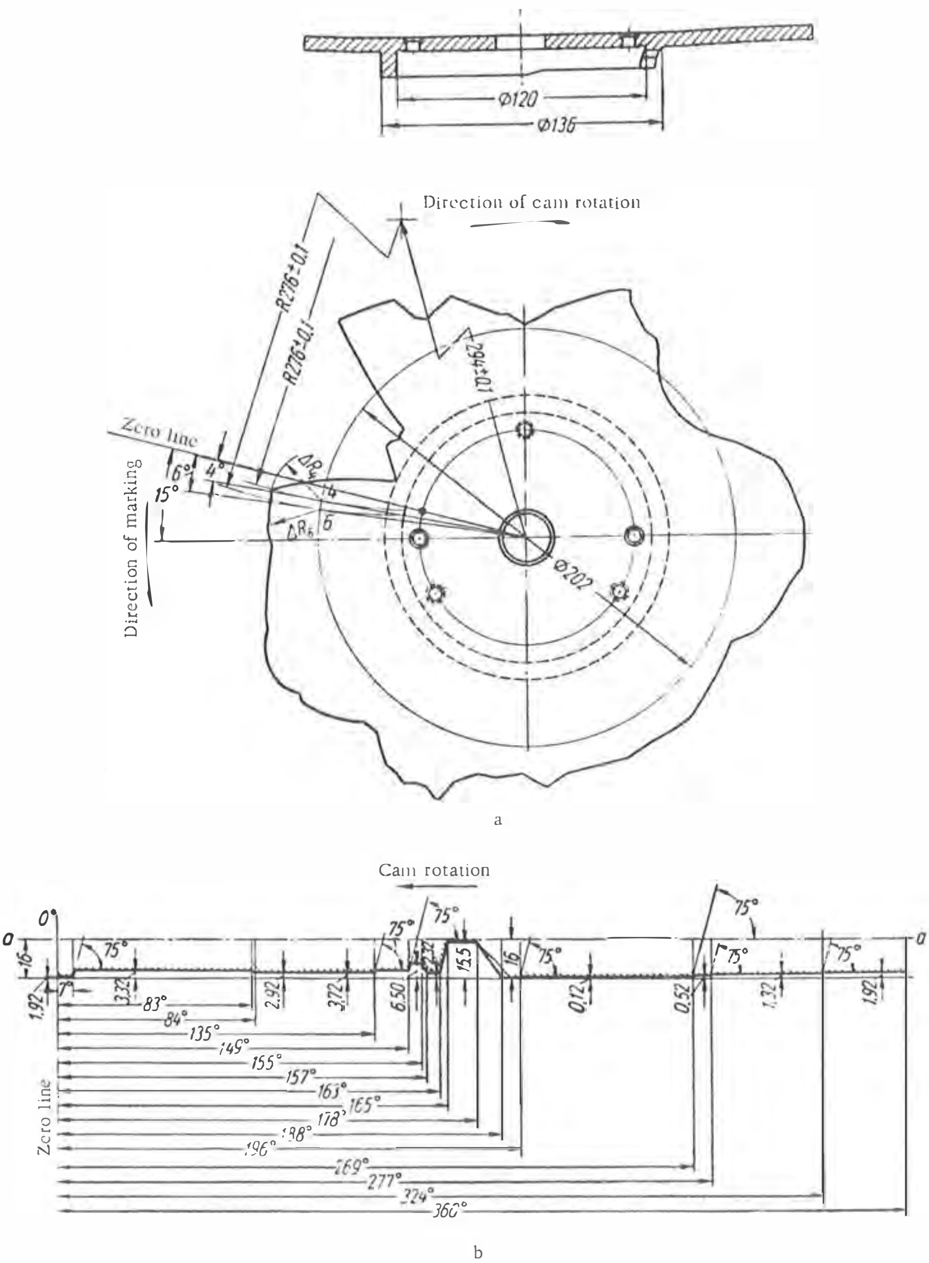


FIGURE 27. Profiles of cams (22) and (23)

Calculation table B: table cam

No.	ΔR	No.	ΔR	No.	ΔR	No.	ΔR	No.	ΔR
4	+25.61	55	+29.21	154	+3.05	221	+5.86	273	+15.50
6	+25.61	56	+27.37	155	+2.09	222	+4.02	274	+13.98
7	+26.41	62	+17.75	156	+1.37	223	+2.25	275	+12.61
8	+26.65	63	+17.27	157	+0.80	224	+0.64	277	+10.52
9	+26.17	64	+16.87	158	+0.56	225	+0.64	281	+5.14
10	+25.37	65	+16.87	159	+0.64	226	+2.01	285	+2.01
11	+25.04	66	+17.19	160	+0.88	227	+3.05	289	+7.39
12	+25.61	72	+27.05	161	+1.37	228	+4.10	291	+7.63
13	+25.61	73	+27.69	162	+2.25	229	−4.98	292	+7.95
16	+24.00	74	+28.09	163	+3.37	230	−5.46	293	+8.52
17	+22.48	75	+28.49	164	+4.66	231	−6.03	294	+9.08
18	+21.20	77	+31.62	165	+6.19	232	−6.27	295	+10.60
19	+20.23	79	+28.73	166	+7.87	233	−6.27	296	+11.89
20	+19.67	80	+28.17	167	+9.72	234	−6.19	297	+13.34
21	+19.57	81	+27.61	172	+18.71	235	−5.94	298	+14.34
22	+20.07	82	+27.29	173	+20.39	236	−5.54	299	+16.63
23	+20.88	85	+33.14	174	+22.00	237	−5.06	300	+18.31
24	+22.24	87	+21.68	175	+23.44	238	−4.42	301	+19.99
25	+23.84	93	+14.30	176	+24.72	239	−3.45	302	+21.60
26	+25.61	95	+14.30	177	+25.93	240	−2.49	309	+15.34
27	+27.29	97	+14.62	178	+26.81	241	−1.45	311	+17.91
28	+28.97	98	+13.01	179	+27.45	242	−0.24	313	+30.10
29	+30.42	99	+11.65	180	+27.85	243	+1.04	314	+31.62
30	+31.38	100	+10.60	181	+28.09	244	+2.41	315	+33.14
31	+32.02	101	+10.28	182	+28.09	245	+3.86	316	+34.58
33	+32.74	102	+10.68	183	+27.85	246	+5.38	317	+38.27
35	+35.71	103	+11.73	184	+27.85	247	+6.91	318	+37.07
36	+37.31	106	+16.87	188	+33.14	248	+8.60	319	+37.95
37	+38.67	107	+17.83	189	+34.34	249	+10.28	320	+38.67
38	+39.79	108	+18.39	190	+34.34	251	+13.82	321	+39.15
39	+40.61	109	+18.39	191	+34.74	254	+14.22	322	+39.55
40	+41.07	114	+13.50	192	+34.66	260	+23.60	323	+39.55
41	+41.23	127	+14.46	193	+35.15	261	+28.33	324	+39.23
42	+40.83	129	+15.67	194	+35.07	263	+27.21	325	+38.75
43	+40.27	140	+14.86	195	+34.91	264	+26.89	333	−21.44
44	+39.31	141	+15.34	196	+34.42	265	+26.25	335	−21.44
45	+38.03	146	+15.99	197	+33.94	266	+25.45	336	−22.24
46	+36.59	147	+14.14	198	+33.14	267	+24.40	337	−21.68
48	+32.66	148	+12.29	200	+31.54	268	+23.12	338	−20.48
50	+33.94	149	+10.60	204	+37.87	269	+21.76	339	−19.67
51	+34.10	150	+8.76	210	+25.29	270	+20.31	341	−19.67
52	+33.54	151	+7.07	212	+23.52	271	+18.71	350	−31.30
53	+32.34	152	+5.46	219	+9.48	272	+17.11	351	−31.30
54	+30.74	153	+4.18	220	+7.63				

In addition to the above-described method of calculating and plotting cams, direct layout and finishing of cams for the S-50 machine can be carried out on the special F-121 machine (Figure 28).

The machine reproduces the operation of levers (24) and (25) of the S-50 machine with the sole difference that the arms of the F-121 machine levers which carry the tool and the master are ten times longer than the short arms of levers (24) and (25) which carry the cutter and the work table.

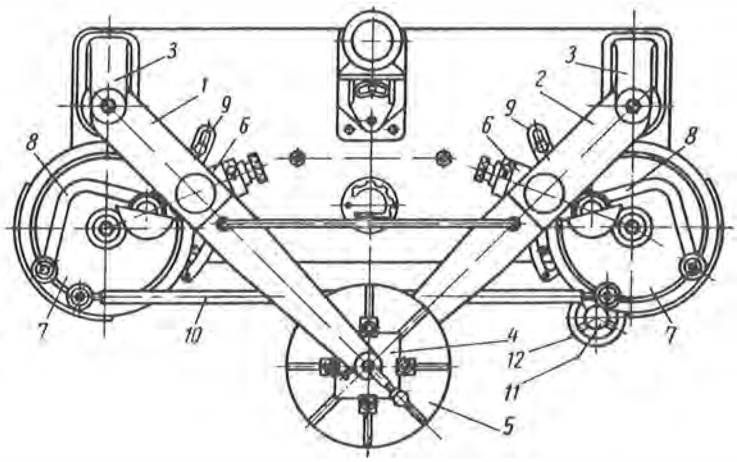


FIGURE 28. Plan view of the F-121 machine for marking, milling and finishing cams for the S-50 machine

The F-121 machine automatically splits the motion of the pin, moving along the master path, into the motions of two tools which form the cam profiles. Its design and operation are as follows. Two arms are articulated on the brackets (3): a cutter arm (1) and a table arm (2), terminated in a pin and a round table (5), respectively. A metallic master (4) with the cutter path to a scale of 10:1 engraved on its surface is fastened to the table. The slides (6) with milling-grinding spindles, having rotary and reciprocating motions, are suspended from the two arms at a distance of 300 mm from the hinge axes.

The index plates (7), capable of rotating about their axes, are located on the machine frame in front of the articulated supports.

The rods (8) have an articulated end placed in an annular T-slot in the upper face of the plates. The other rod end fits in an arc-shaped slot in levers (9), fastened to the arms. The two plates are connected by means of rod (10), whose articulated ends are fixed in the T-slots of the plates, thus ensuring equal angular displacements for them. On the plate circumference 360 equally spaced teeth are cut and mesh with a small gear (11). The gear is fitted on the same axis with the handwheel (12). The cam blank is mounted on the upper flange of the index plate. The cam-manufacturing procedure is as follows: the cams are first marked in the F-121 machine and then subjected to rough machining using general-purpose equipment. After this the cams return to the F-121 machine for finish milling and contour grinding.

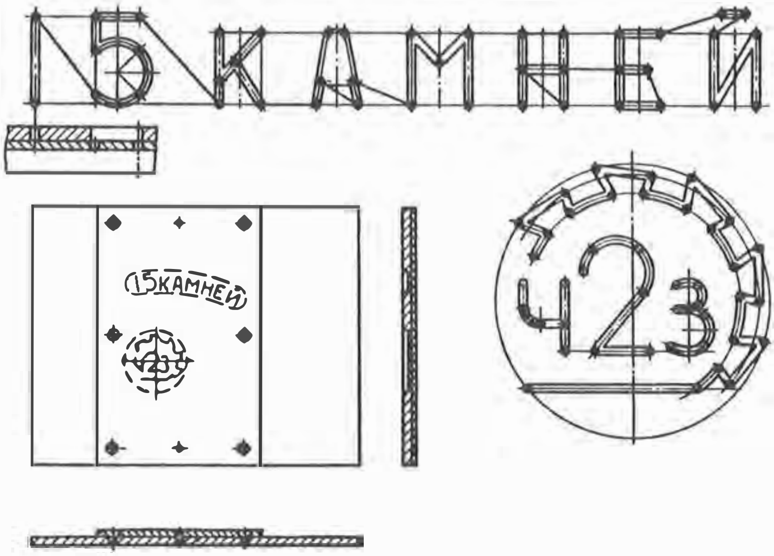


FIGURE 29. Master for the F-121 machine

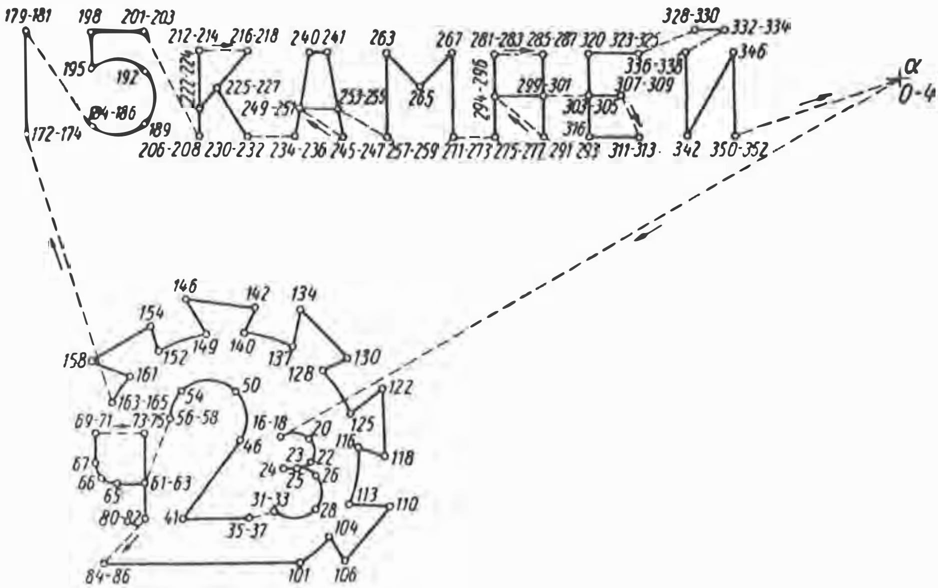


FIGURE 30. Cutter path for marking the cams for the S-50 machine

For marking the cams, center punches are mounted in the spindle collets. The pin at the end of arm (1) enters the slot on the master (4) and moves along the path. The right-hand index plate is rotated to the required angle (equal to the path sector) by means of the handwheel (12). The plate rotates arm (2) and table (5) by means of rod (8) and lever 9. Simultaneously, it rotates the left-hand plate through the same angle by means of rod (10). Rod (8) on the left plate is in this case disconnected from arm (1), and the pin on the end of the latter is free to move in the master slot.

The spindle center punches copy the pin paths on the blanks to a scale of 1:3. Depending on the path profile, the index plates are connected by rod (8) either with arm (1) or with arm (2). After the marking the cams are rough-machined using general-purpose equipment, and are then positioned anew in the F-121 machine. The center punches in the spindles are replaced successively by an end-milling cutter and a mandrel with a grinding disk.

The master for the F-121 machine along with the form to be marked is shown in Figure 29, while Figure 30 gives the cutter path for marking the profile of the cams for the S-50 machine.

The F-121 machine reduces to a half or a third the work entailed in the manufacture of the cams and eliminates the rotation-angle error in the cam profile.

Figure 31 shows the tool used in the S-50 machine: a) single-lip cutter, b) collet for gripping the cutter.

The S-187 semiautomatic two-spindle contour-milling machine (Figure 32), functions in a manner similar to that of the S-50 machine and is produced by the Soviet industry. Its production rate is almost twice that of the S-50 machine, because of its twin spindles; but on the other hand it requires a much finer adjustment to ensure identical contours on the two simultaneously machined parts. In contrast with the S-50 machine, part and tool move along Cartesian coordinates in this machine. The machine slide (1) (Figure 33), together with the two parts fastened to it, is moved vertically by means of a rack and a gear segment. The bed (2) carrying the tool spindles moves in a horizontal plane: longitudinally for milling-depth control (by stops), and laterally for profile cutting. The method of cam calculation is based on the cutter path and on the analytical or graphical-analytical measurement of the point coordinates.

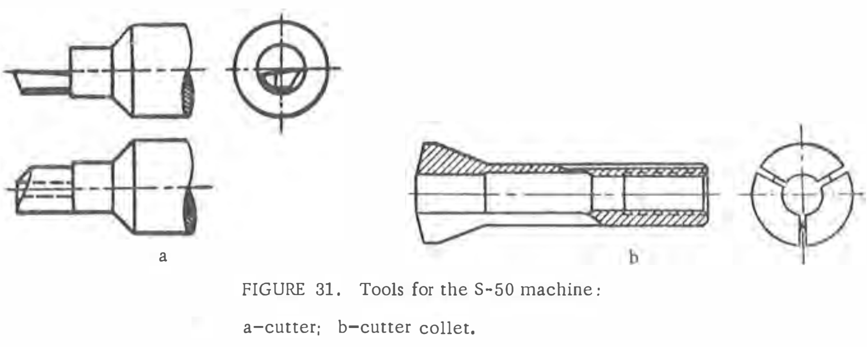


FIGURE 31. Tools for the S-50 machine:

a—cutter; b—cutter collet.

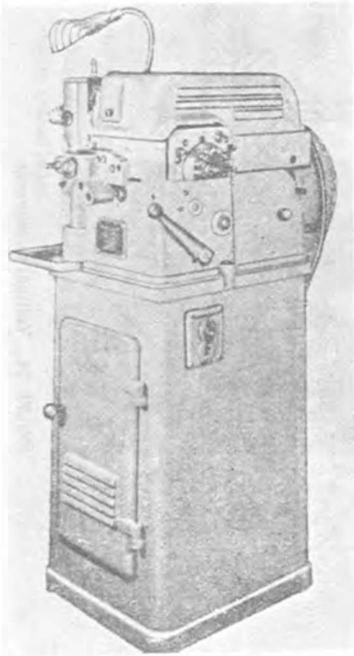


FIGURE 32. S-187 semiautomatic two-spindle milling machine

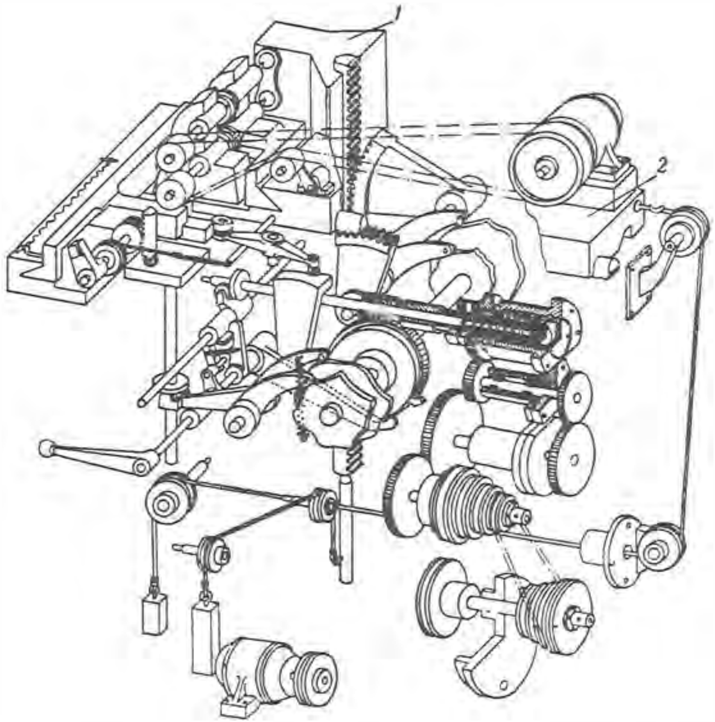


FIGURE 33. Kinematic diagram of the S-187 semiautomatic two-spindle milling machine

Technical data, S-187 machine

Number of parts machined simultaneously . . .	2
Maximum machining surface, mm	45 x 45
Maximum thickness of parts, mm	14
Maximum cutter diameter, mm	6
Spindle speed, rpm	7400
Time for one working cycle, sec	From 10 to 125
Electric motors:	
tool	0.65 kw, 2895 rpm
camshaft	0.4 kw, 1400 rpm

Inspection of Milling and Turning Operations

The facing, boring, and milling of recesses in plates and cocks are followed by inspection of the depth of the recesses and of the contour position relative to the working holes. This inspection is carried out using either a comparator or a special gage.

The depth of counterbores is measured using a vertical dial gage or a vertical micrometer (Figure 34). The use of a dial gage, with scale divisions of 0.01 mm, is less time-consuming. The quality of the surfaces machined on the S-81A and S-50A machines is inspected with the help of magnifying glasses with a magnification of 5×, 16×, or, rarely, 32×.

FIGURE 34. Vertical micrometer

The machining of holes in plates and cocks is a complex and crucial operation. The diameter tolerance in most cases is 0.005 mm; the surface-finish quality corresponds to class 9–10 at least; and the interaxial-distance tolerance is 0.0075–0.010 mm.

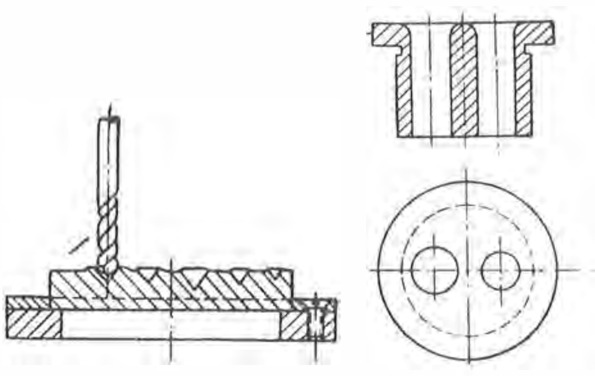
These severe requirements are satisfied by subjecting the holes to preliminary and final machining stages.

The preliminary machining consists either in center marking followed by punch piercing, center marking followed by drilling, or punch piercing without center marking.

The final machining consists in shaving the holes in special dies. Reaming has found no application in the final machining of holes, as it is both a less accurate and a less productive process than shaving. Some holes are threaded.

Drilling

The watch industry and many other branches of the precision-instrument industry make extensive use of the method of drilling holes according to center-punch marks, this method being superior to the method of drilling in jigs. The part to be drilled lies freely on the drilling-machine table or on an open support, and is easily placed manually under the drill (Figure 35, a). The drill is guided by the center-punch mark. The use of jigs, on the other hand, requires considerable time for the positioning and fastening of the part in the jig, and removal of the part after drilling.



a) b)

FIGURE 35. Drilling holes:

a–according to center-punch marks; b–jig bushing for drilling closely spaced holes.

If only two or three holes are drilled using a jig, the auxiliary time may turn out to be longer than the drilling (basic) time. When a large number of holes are drilled in the same part, it may happen that not all the holes can be drilled through in one setting, and the part has to be repositioned in the jig. An especially complex bushing is necessary for drilling closely spaced holes (Figure 35, b). Jig drilling is less accurate since a drilling error, in addition to the jig inaccuracy, results from the clearance between the drill and the jig-bushing hole.

The accuracy of the distance between centers is improved by drilling according to center-punch marks.

If the number of holes is small, they are drilled on the S-3M (Figure 36) or S-12M (Figure 37) bench-type vertical drilling machines.

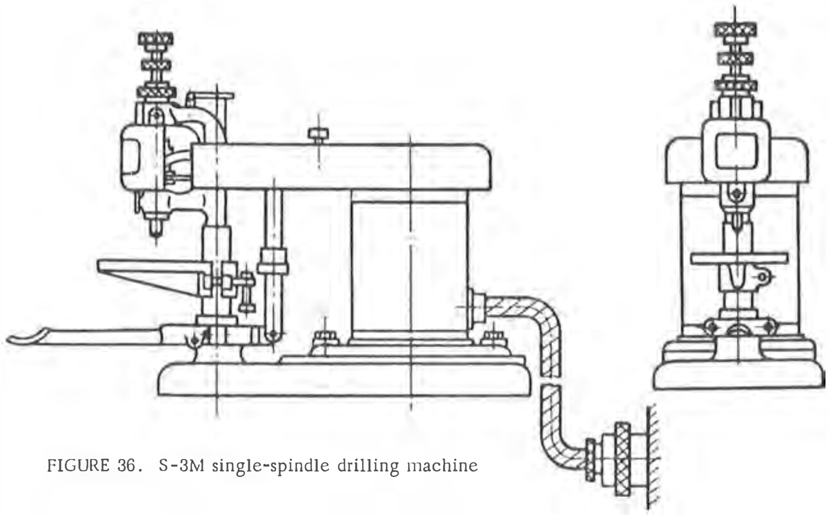


FIGURE 36. S-3M single-spindle drilling machine

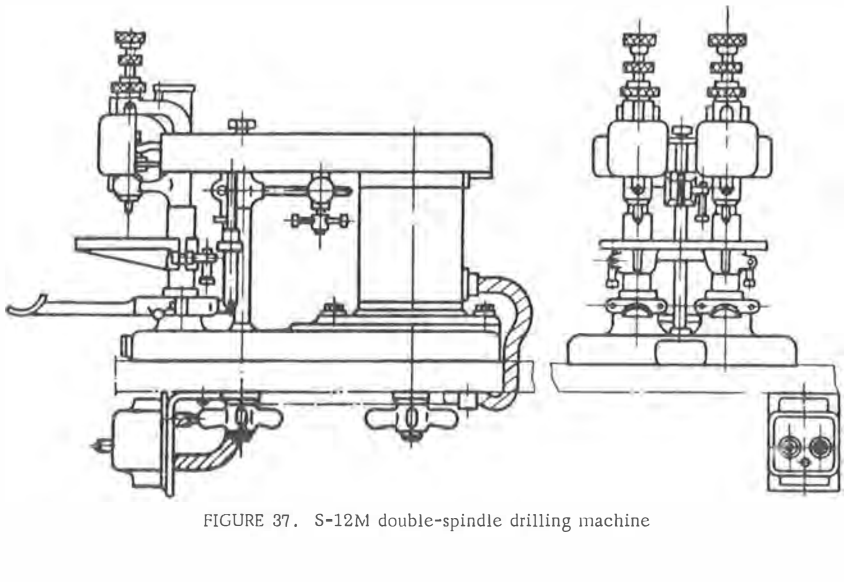


FIGURE 37. S-12M double-spindle drilling machine

For a large number of holes the S-44A semiautomatic machine is used. The second spindle in the S-12M machine is frequently used for countersinking the holes drilled by the first spindle.

Holes in brass, of diameters from 0.2 to 2.0 mm, can be drilled on the S-3M and S-12M machines. The spindle speeds of these machines are 6000 and 7500 rpm, respectively.

The production rate of the drilling machine depends on the mechanical properties of the metal, the hole diameter, and the spindle rpm.

The mechanical strength of drills 0.2 to 0.7 mm in diameter is poor and therefore the drill must be withdrawn from the work from time to time during drilling for chip removal (Table 5).

The cutting conditions for drilling LS63-3 brass at n = 6000 rpm are given in Table 6.

TABLE 5

Number of drill withdrawals as a function of the diameter and depth, mm

Drill diameter	Drilling depth								
	0.8	1.1	1.4	1.7	2	2.3	2.5	2.9	3.2
	Number of drill withdrawals								
0.2	1	1	1	2	2	3	3	3	4
0.3	—	1	1	1	2	2	2	3	3
0.5	—	—	—	1	1	1	2	2	2
0.7	—	—	—	—	—	1	1	1	2

The drilling (basic) time is determined by:

$$T_{dr} = \frac{l_1 + l_2}{s_m},$$

where l_1 = the drilling depth, mm;
l_2 = the drill approach, mm;
s_m = feed, mm/min, from Table 6;

with l_2 being taken from $$l_2 = \frac{D_2}{2}\cot\text{an}\,\varphi,$$

where φ = half the drill-point angle;

The holes are also countersunk on the S-3M and S-12M machines.

TABLE 6

Speeds v m/min, and feeds s, mm/min, as a function of the diameter D, mm, for drilling LS-63-3 brass

D	s_m	v	D	s_m	v	D	s_m	v	D	s_m	v
0.2	36	3.75	0.6	150	11.30	1.0	280	18.84	1.3	350	24.50
0.3	48	5.65	0.7	186	13.20	1.1	310	20.70	1.4	383	26.40
0.4	78	7.54	0.8	227	15.1	1.2	330	22.60	1.5	395	28.40
0.5	114	9.40	0.9	250	17.10						

The S-44A ten-spindle semiautomatic drilling machine is used in watch production for drilling and countersinking holes in plates and bridges. The machine consecutively positions the axes of the holes to be machined opposite the drilling-spindle axes (Figure 38).

The machine can drill consecutively, in one chucking, from 20 to 50 holes of ten different diameters with any location of the holes on the part within the limits of a circle of 46 mm diameter. The cutting tools used are twist drills, pointed drills and countersinks, held in the spindle collets. The center-punched part is positioned on a pin plate on the carriage. The carriage moves in a vertical plane and positions the center-punched holes in front of the drills.

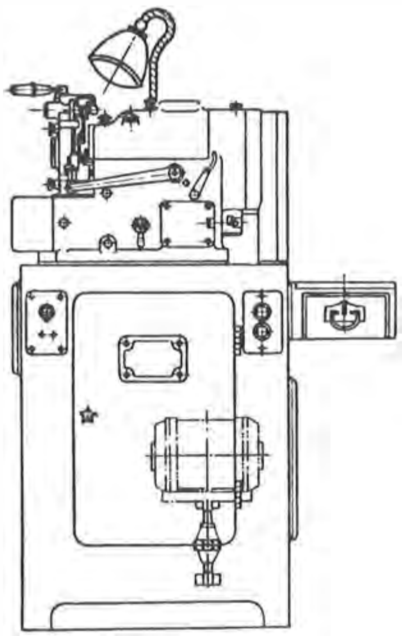


FIGURE 38. S-44A semiautomatic drilling machine

After all the holes having the same diameter have been drilled, the spindle barrel is indexed 1/10 revolution, and the next spindle, with a drill of different diameter, is fed into working position. The machine is automatically switched-off after all the holes have been drilled, and the work carriage is lifted to the loading position for reloading. The part is loaded and removed manually.

The kinematic diagram of the machine is shown in Figure 39. The electric motor powers the reduction-gear shaft, which, in turn, drives the spindle shaft through a claw clutch. The spindle shaft powers, through a friction clutch, the drilling spindle which is in working position.

Power is transmitted to the reduction-gear output shaft through two worm-and-wheel sets and a pair of spur change gears. The output shaft powers the camshaft through a pair of fixed gears. Six camshaft speeds are achieved by changing the change gears.

The camshaft carries the following cams: stud-disk indexing (A), barrel indexing and locking (B and C), spindle feed (D) and carriage lift (E).

The stud-disk indexing cam A is set on the front end of the camshaft (Figure 40). By acting on lever (1) and slide (2) the cam displaces the pawl (3) to the right and thus indexes the stud disk by one tooth on the ratchet wheel. The slide and pawl are returned to their initial position by the spring (4).

The barrel-indexing cam B and the barrel-locking cam C are fastened on a common bushing freely mounted on the camshaft (Figure 41). They are controlled by the stop screws (1) on the stud disk (Figure 42).

When the stud disk is indexed by one tooth, stop screw (1) engages the toe (2) and lifts lever (3). The right-hand arm of the lever drops and frees the pawl (4), which engages, under the influence of the spring (5), a groove in ring (6), fastened rigidly to the camshaft. Both cams B and C begin to rotate. The locking cam C pulls the lockpin (1) (Figure 41) out of the barrel slot and the indexing cam B indexes the barrel by 1/10 revolution through levers (2) and (3). The lockpin engages the next slot on the barrel. Both levers are returned to their initial positions by springs.

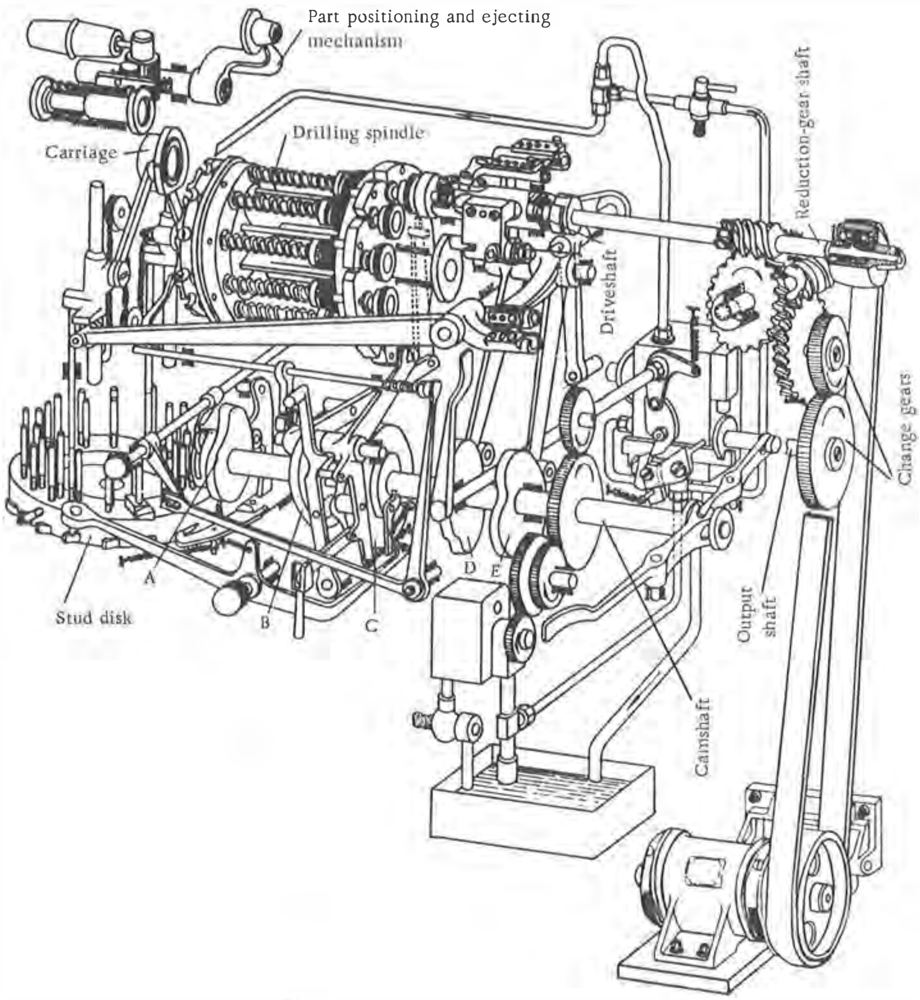


FIGURE 39. Kinematic diagram of the S-44A machine

At the end of a complete cam revolution lever (3) (Figure 42) re-engages the pawl (4) and pulls it out of the groove in ring (6). This interrupts the cam rotation until the next indexing of the spindle barrel. The handle (4) (Figure 41) serves for manual rotation of the spindle barrel.

The spindle-feed cam D (Figure 43) and the carriage-lift cam E (Figure 44), operating through lever systems,feed the drilling spindle and lift the carriage when the stud disk indexes. The lever systems are equipped with devices for feed and lift adjustment.

At the end of the machining cycle the lever (1) (Figure 44) rotates shaft (2) under the action of a plunger, and lifts the carriage into loading position.

The device for automatically stopping the camshaft at the end of the machining cycle is shown in Figure 45. The driving gear (1) powers the camshaft (2) through the key (3). The camshaft is switched off automatically at the end of the machining cycle by the stop (4) on the stud disk engaging the catch (5).

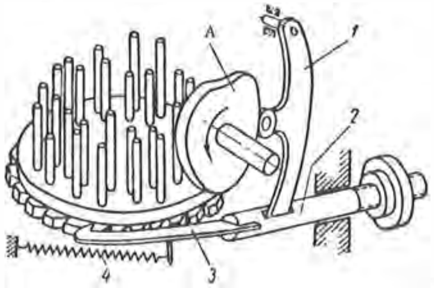


FIGURE 40. Stud-disk indexing mechanism

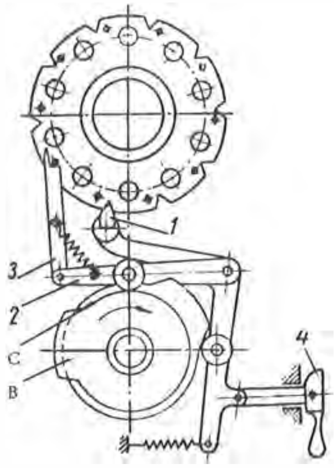


FIGURE 41. Spindle-barrel indexing mechanism

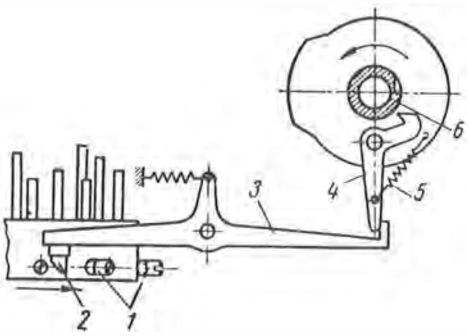


FIGURE 42. Actuation mechanism for cams B and C

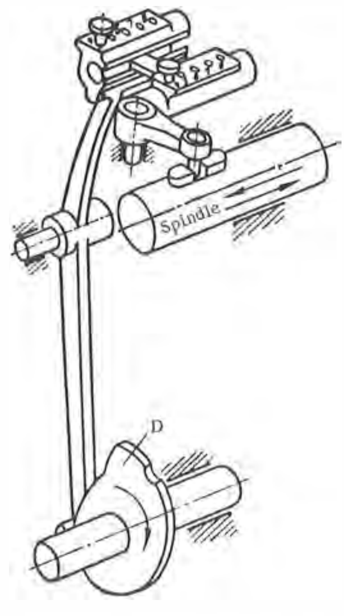


FIGURE 43. Drilling spindle feed mechanism

The stud disk (see Figure 40) positions the part definitely relative to the drilling-axis spindle. The disk has threaded holes located along two concentric circles into which are screwed hardened studs. The number of holes on each circle is equal to the number of holes to be machined. The studs support the carriage posts. The height of each pair of diametrically opposed studs determines the position of the carriage relative to the spindle axis. Stops for automatically stopping the camshaft at the end of the machining cycle are mounted on two studs. The disk makes one revolution during the machining cycle.

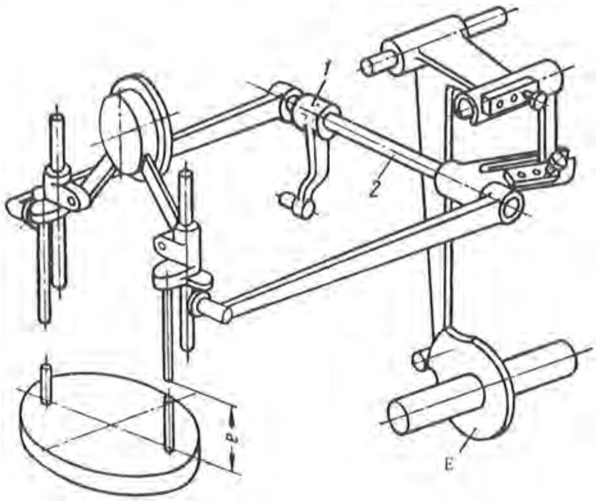


FIGURE 44. Carriage-lifting mechanism in loading position

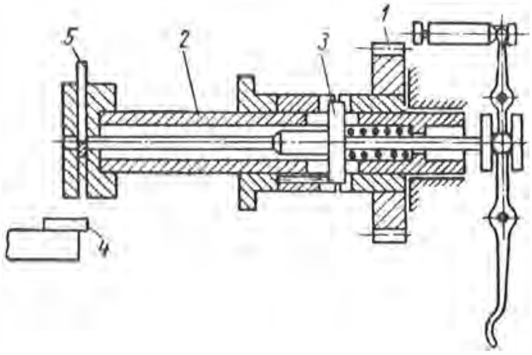


FIGURE 45. Automatic camshaft-stopping device

Ten identical drilling spindles are mounted in the spindle barrel. At the back end of each spindle (3) (Figure 46) is mounted a bushing (1) with a graduated threaded ring (2), which transmits rotation to the spindle from the driveshaft friction clutch and permits the drilling depth to be adjusted to an accuracy of 0.01 mm.

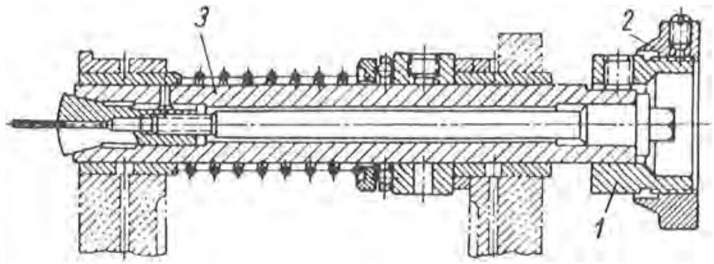


FIGURE 46. Drilling spindle

The carriage-motion mechanism is shown in Figure 47. The carriage (1) is rigidly fixed to the right-hand lever (2) and articulatedly hinged to the left-hand lever (3). The other ends of the two levers have articulated connections with slides (4) and (5). The slides move on columns. Carriage posts (6) are mounted in the slides and they engage the studs on the stud disk under the weight of the whole carriage system and the tension of spring (7). The left-hand post rests on the outer stud, and the right-hand post engages the inner stud. By varying the height of the studs the motion of the carriage in the xy plane is controlled.

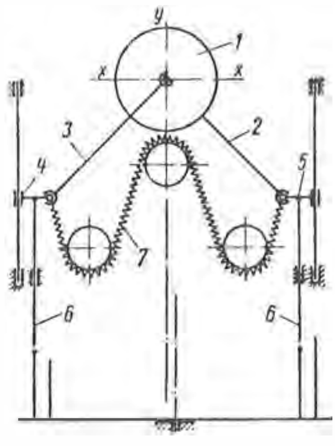


FIGURE 47. Carriage-motion mechanism

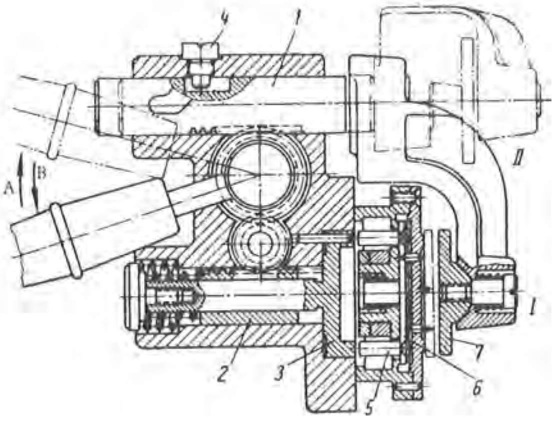


FIGURE 48. Device for clamping and ejecting the part

The device for ejecting the machined part and mounting the next part on the holding plate is shown in Figure 48. If the handle is rotated in the direction of arrow A, the rack shaft (1), the rack (2) and the pusher (3) are fastened to the right. The rack shaft, in moving to the right, is simultaneously rotated by guide pin (4) and a helical flute and assumes position II. Pusher (3), pressing on the pins (5), forces plate (6) to the right and removes the part from the setting pins. After the next part has been placed on the pins by the operator, the clamping pad (7) is returned from position II to position I by rotating the handle in the direction of arrow B. The part is thus pressed onto the setting plate. The rack shaft and the clamping pad are moved somewhat to the right by a spring, and so allow the carriage to be lowered into working position.

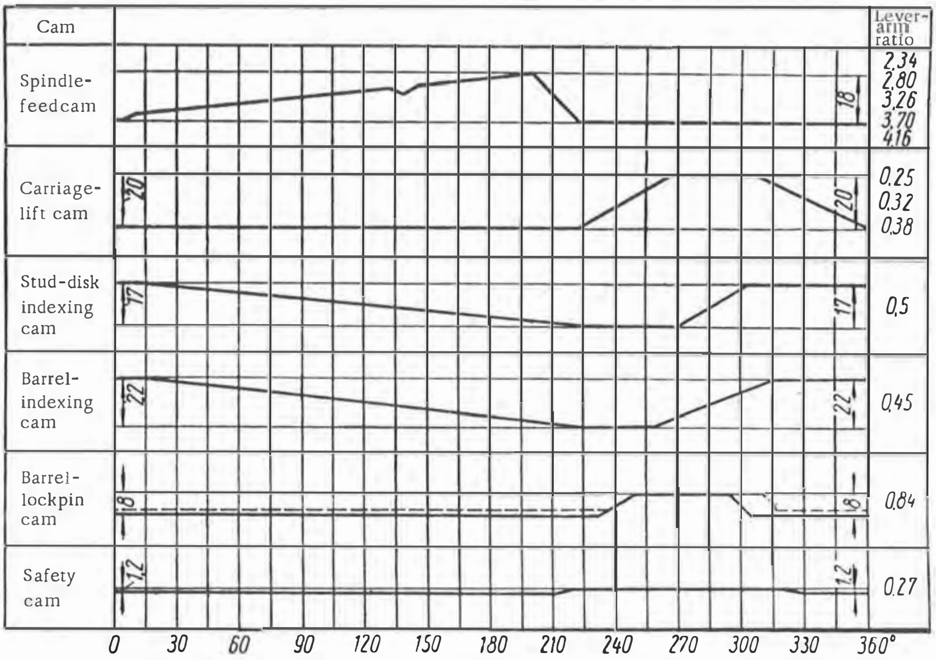


FIGURE 49. Cycle diagram for the S-44A machine-camshaft cams

Figure 49 is the cycle diagram for the camshaft cams. It should be pointed out that the idle movements constitute 47% of the cycle time in this machine, and that in spite of this fact the machine is very productive: 56 holes can be drilled in 1 minute. One operator can service from 4 to 5 such machines.

S-212 semiautomatic drilling machine. This machine (Figure 50) serves for drilling lateral holes in plates.

The S-212 machine has a two-position plate in which a part is manually set on the locating pins while another part is being machined. The holes for the winding stem in the watch plate are successively center-marked, drilled and bored by three tools on this machine.

The machined part is automatically removed from the locating pins. The machine motions are controlled by cams mounted on the camshaft, which can rotate at 5.1, 6.4, or 8 rpm. One part is machined per camshaft revolution. The maximum dimension of the machined part is 45 mm, the maximum thickness 5 mm, and the maximum hole diameter is 2 mm. The time taken to machine one part varies between 8 and 12 sec. The drilling spindles revolve at 10,300 revolutions per minute and a 0.6 kw, 3000 rpm, electric motor is used.

Technical data, S-44A machine

Maximum drilling diameter, mm	3
Minimum drilling diameter, mm	0.3
Maximum drilling depth, mm:	
brass	5
steel	3
Accuracy of hole diameter, mm	0.01
Accuracy of distance between centers, mm	0.02—0.03
Drilling-spindle speed, rpm	10,500
Number of camshaft speeds	6
Time for one camshaft revolution, sec	2.85—0.92
Drilling-spindle feed rates, mm/rev	0.015—0.090
Electric motor	0.65 kw, 2800 rpm

The A-224 semiautomatic machine, similar in design to the S-212 machine, is used for center-marking, drilling and threading two lateral holes on the plate to take the dial leg screws. The two holes are machined consecutively and the loading plate is rotated 180° about its axis to machine the second hole. Holes of 0.3 to 1.2 mm diameter are threaded. The threading spindle revolves at 3260 rpm for threading, and at 5450 rpm for tap withdrawing.

Hole Shaving in Dies

The high accuracy required of the holes in plates and bridges is now achieved by shaving them in dies. The drilled (or pierced) holes have an allowance for shaving (Table 7), which must compensate for the deviations in the diameters and interaxial distances which resulted from earlier operations.

TABLE 7

Shaving allowance for holes in plates and bridges

Diameter of hole to be shaved, mm	Allowance on the diameter for:	
	steel $\sigma_b > 80$ kg/mm^2	brass $\sigma_b < 50$ kg/mm^2
0.25—0.50	0.08	0.05
0.50—1	0.12	0.08
1—1.5	0.18	0.12
1.5—2.5	0.25	0.20
2.5—3.5	0.40	0.30

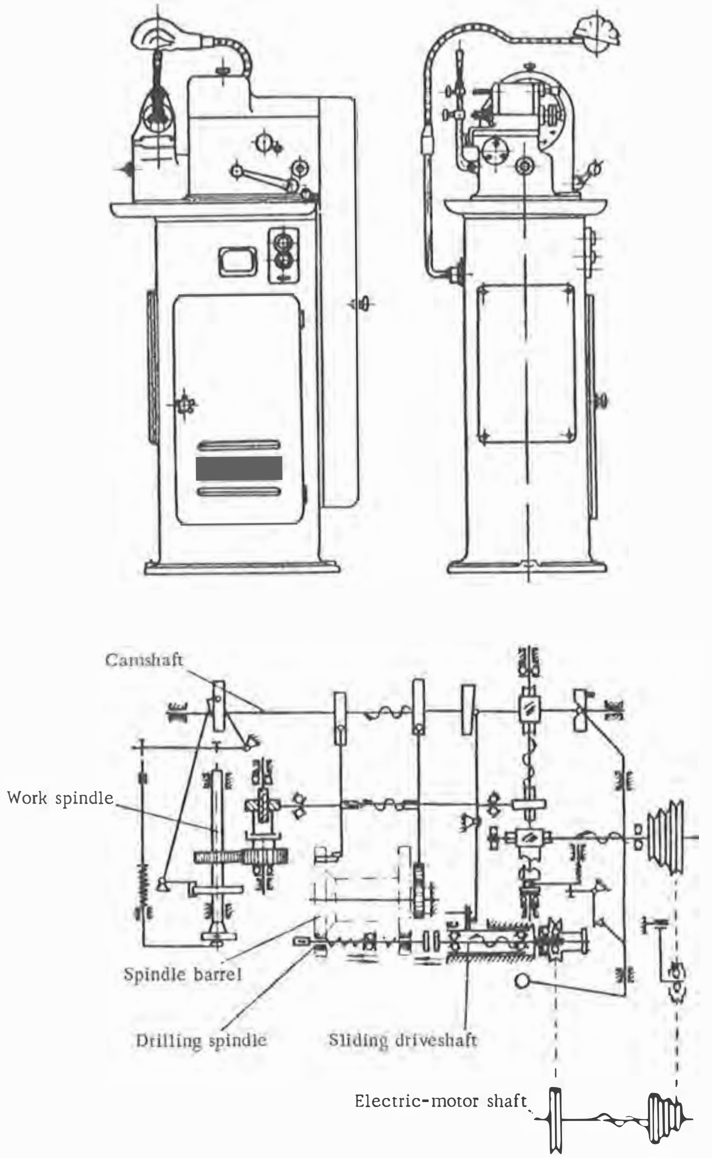


FIGURE 50. General view and kinematic diagram of the S-212 semiautomatic drilling machine

For blind holes, the allowance is reduced by 25–30%.

Shaving is the final hole-machining operation, and all other operations must therefore be concluded before shaving.

The dimensions of the holes obtained by shaving are very accurate and the process itself is very productive. All the holes in a part, both through holes and blind holes, can be shaved in one stroke of the press. Up to 24 holes are shaved in the plates of pocket and wristwatches by one die.

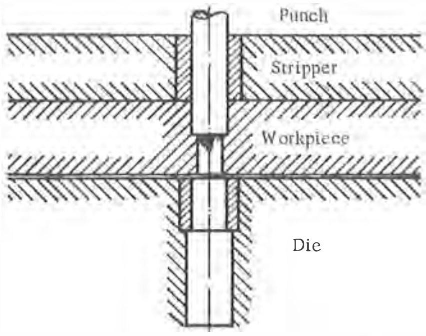


FIGURE 51. Schematic representation of hole shaving

The process of hole shaving consists in the removal of chips by means of a punch (Figure 51). The punch must have a well-finished face surface. Any burrs on its edges would lead to metal build-up at the burr and to the appearance of deep longitudinal scratches on the hole surface. Metal build-up on the punch is likely to occur even with a good surface finish and, in order to prevent it, forced lubrication of the punches (see below) is used in some shaving dies.

The punch diameter must be larger than the diameter of the shaved hole by the value of the hole contraction. Hole contraction occurs as a result of the blunting of the punch end which then not only cuts, but also deforms the metal fibers. If the hole is pierced by the punch, the metal fibers are bent to a considerable depth, and an elastic deformation occurs. The hole contraction also depends on the extent to which the shaving punch removes a uniform chip around the circumference.

Hole contraction is determined by the formula

$$D_{\text{punch}} = D_{\text{hole}} + A.$$

For brass A is 0.005 to 0.015 mm.

Design of shaving dies. In the shaving die shown in Figure 52 the punch and the locating pins are placed in the upper die shoe together with the stripper, and the plate or bridge to be shaved is set in the lower shoe, and is positioned by the guide pin (2). When the ram (1) is lowered the pins (3) take over the positioning function from the guide pin (2).

The advantage of this design lies in the fact that both the punches (4) and the locating pins (3) are located in the stripper (5) and the punch holder (6), thus ensuring a fixed relationship between the locating and the shaving elements. This design gives both highly accurate distances between centers and a uniform removal of the allowance around the circumference.

In some dies the locating pins (3) are in the lower shoe. The holding and locating system is separated, in this case, from the punches, and this can lead to the shifting of the whole punch system relative to the drilled holes. In many cases this leads to imperfect shaving due to the small allowances.

The die (8) with the punch guide bushings (9) which guide the punches and permit the passage of chips is fastened in the lower shoe of the die set. The bushing (9) sometimes protrudes from the die by a height equal to the depth of the recess in the part in order to prevent the buckling of thin parts (Figure 53). Dies having recesses instead of bushings are used when the hole to be shaved has a deep countersink at the exit. The presence of chips in the recess is evidence of the correct functioning of the punch. The chips are removed from the recesses by a jet of compressed air. The hole entrance must not have a countersink if it is to be shaved. The ram (1) (Figure 52) is guided in the fixed stripper (5) by the guideposts (7). The bushings (11) which guide the punches are fastened in the stripper. The use of bushings reduces the wear on the stripper and increases the manufacturing accuracy.

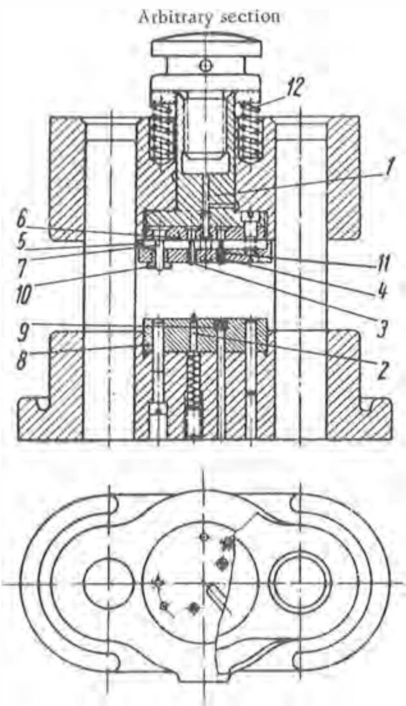


FIGURE 52. Shaving die

When the hole diameters are small, the accuracy with which they can be machined in a jig-boring machine at considerable depth is poorer than the accuracy with which bushing holes can be machined. If the bushings are accurate with respect to run-out and diameter, it is more convenient to replace worn-out bushings [by new ones] than it is to replace the stripper, since the stripper is the most critical part in the die set.

The part to be shaved is manually put on the guide pin (2). The upper shoe is forced to descend with ram (1) by the spring (12) and transfers the part from the guide pin (2) to the pins (3). When the stripper engages the work the ram advances along the guide bushing (10). The punches emerge and penetrate the holes to be shaved. The stripper (5) continues to press the part against the die.

The design of a shaving die with forced punch lubrication, which reduces punch wear and prevents chip adherence, is shown in Figure 54. This design also provides a fixed relationship between the locating and shaving elements.

The design of this die is somewhat more complex than that of the die described above, but this is compensated for by a greater stability in operation.

The requirements for the shaved holes in the plates and bridges of pocket- and wristwatches are 0.007 mm maximum deviation of the distances between centers, 0.005 mm maximum deviation of hole diameters. Accordingly, the punch must be so well fitted in the stripper bushing that oil can flow between them only under the very high pressure created by the stripper upon impact of the upper shoe. The spring-loaded plungers in the oil passages in the die-set posts serve to control the oil pressure.

In order to increase the shaving accuracy and to lengthen the die life, plates and cocks are now shaved twice, and sometimes even three times.

The allowance for the last operation is 0.01–0.015 mm on the diameter. The service life of such a die (between regrindings) can be as much as 80,000 strokes. The punches and dies of shaving-die sets are sharpened directly in the shoes, without dismantling them.

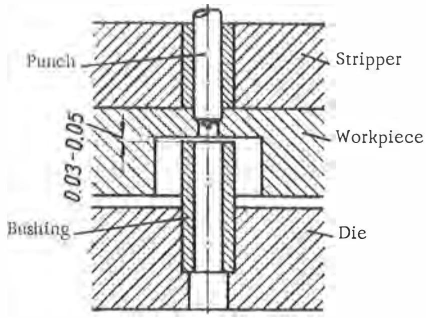


FIGURE 53. Shaving-die guide bushing

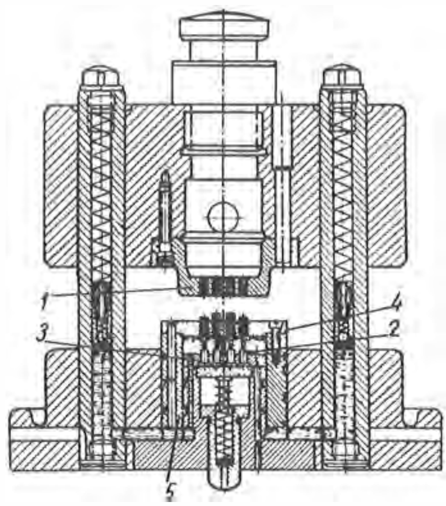


FIGURE 54. Shaving die with forced punch lubrication: 1–die; 2–punch; 3–punch holder; 4–stripper; 5–ring.

Shaving dies are expensive tools, and the following operational rules have accordingly been established:

1. Parts to be shaved must be inspected before shaving in order to ascertain the existence of all the holes which are to be shaved. The holes are inspected by a gage consisting of a plate and pins on which the part is freely fitted. If any of the holes is missing, the part will obviously not fit on the pins. The inspection can also be conducted using a projection device.
2. The parts are positioned according to base holes or along the contour, but in such a way as to ensure positive location.
3. The part must be carefully cleaned and washed to remove chips and dirt, and must fit tightly in the die or stripper.
4. It is not recommended that holes whose depth is larger than three diameters be shaved. A higher ratio might lead to deflection of the punch.

Measurement of Hole Center Coordinates

The position of the hole centers in plates and cocks is given in Cartesian coordinates which are also used to define the centers of the recesses, so as to provide uniform system of designations in the drawings. The values of the coordinates and the radii of the recesses are listed in a table. The centers of holes and radii are projected on a horizontal plane and are designated by numbers with subscripts.

The coordinates x = 100 mm, y = 100 mm are assigned to the center-wheel center or to the centers of the minute and hour hands in watches. This ensures that the coordinates of all points on the part will always be positive, that is, the part will always be situated in the first quadrant of the coordinate system.

Figure 55 shows the position of the train bridge with the table of coordinates for the basic points. The diameters of the holes in cocks and plates are measured using plug gages or toolmakers' microscopes. The coordinates of the hole centers may be measured using the UIM-1 universal measuring microscope (Figure 56), the Hauser (Switzerland) jig-boring machine (models 1 and 2A), and the Hauser coordinate-measuring machine (model R-324).

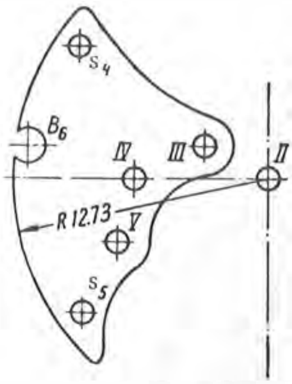


FIGURE 55. Coordinates of the holes in the train bridge of "Pobeda" watches

Point No.	Point coordinates x	y
II	100	100
III	96.565	101.394
IV	93.500	100
V	92.825	96.804
S_4	90.640	106.5
S_5	90.750	93.400
B_6	87.845	101.500

The unit of division on the scales of the above-listed machines is 0.001 mm.

The UIM-1 universal measuring microscope is little used for coordinate measuring because it has neither a circular rotary table nor a superimposed-image head.

The machine mostly used for measuring the coordinates of watch parts is the model-1 Hauser coordinate-marking machine (Figure 57).

The limit of displacement of this machine is 100 mm × 100 mm.

A 120 mm diameter three-jaw chuck is mounted at the upper end of the lower vertical spindle of the machine, the lower end of which spindle carries a disk with angular divisions and a vernier of 0°02' accuracy. Parts are positioned in this machine with an accuracy of 0.002 mm. The reading accuracy has been increased to 0°00'05" in the latest models.

The R-324 coordinate-measuring insturment (Figure 58) uses a gear- and-rack mechanism for moving the slides. There are no micrometric screws. The coordinates are measured by two lateral microscopes with reticules (Figure 59). The central microscope is exchangeable and the magnifications available are 35× and 45×.

The part is positioned either on a flat table with independent coordinate displacements, or on a rotary table with scale divisions of 0°00'05" on the vernier (Figure 60). The linear positioning accuracy is 0.002 mm.

The point coordinates are measured in the No. 1 machines and the R-324 instrument by positioning the part on the machine table, aiming at the center of the hole to be measured, recording the measured coordinates and calculating the deviations, if any.

For measuring, the part is positioned on the table either by centering and then locking, or by setting according to two holes.

When using the first method, the center of hole 1 (the centering hole) (Figure 61) is made to coincide with the center of the microscope reticule and the part is then fastened to the work table. The center of the table must coincide with the center microscope-grid cross hairs and the machine slides be set in the middle position.

The center of hole (2) (the locking hole) is made to coincide with the cross hairs of the microscope reticule by displacing the slides according to the coordinates x_2y_2 of the locking point and rotating the part table from position 1' into position 2. The table is locked in this position.

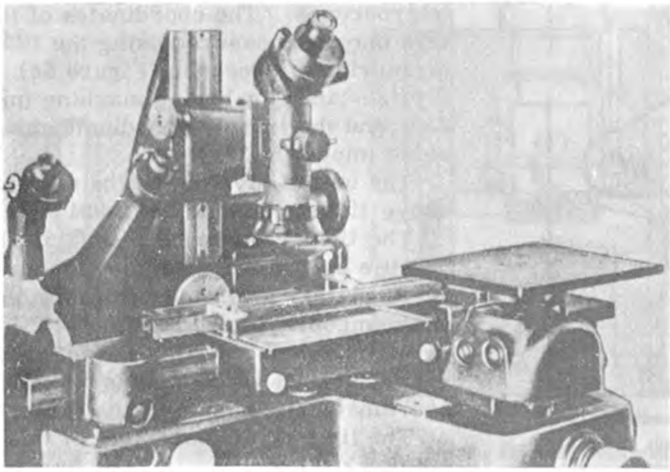


FIGURE 56. UIM-1 universal microscope

FIGURE 57. Model-1 Hauser coordinate-marking machine

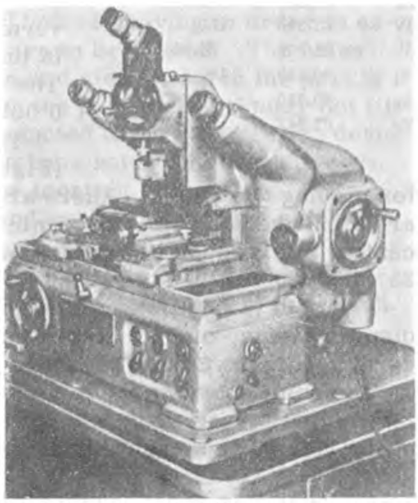


FIGURE 58. R-324 Hauser coordinate-measuring instrument

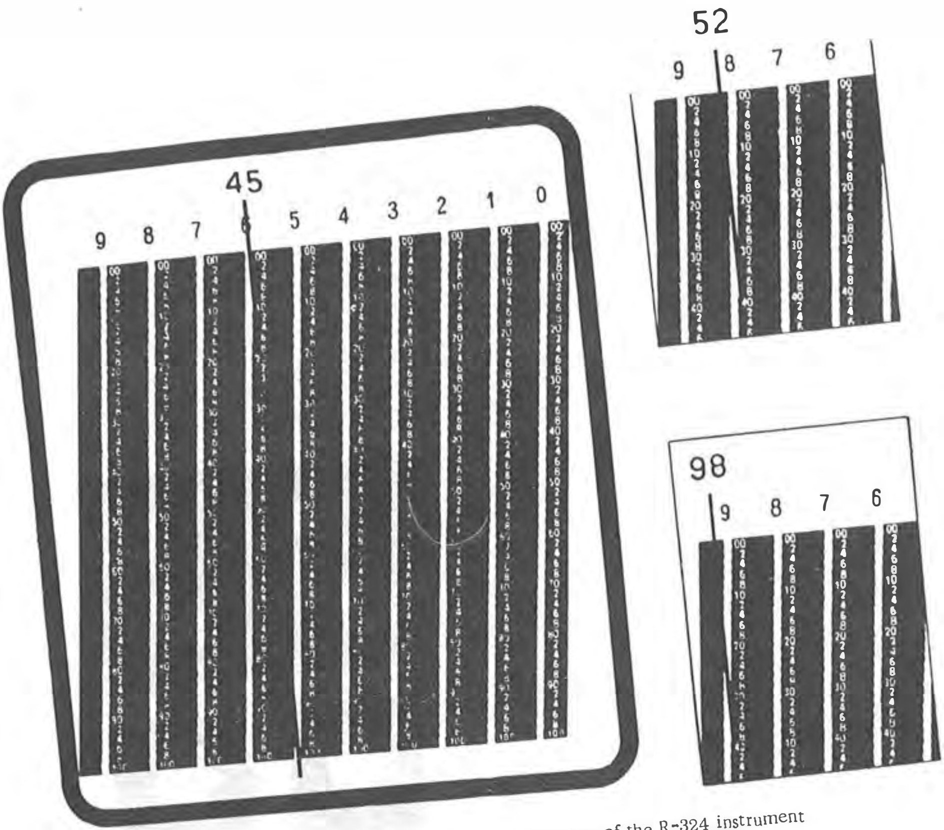


FIGURE 59. Reticules of the side microscopes of the R-324 instrument

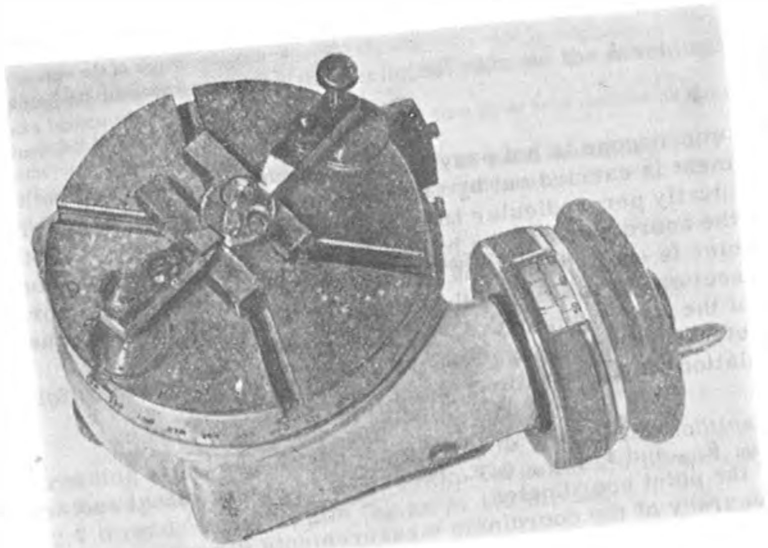


FIGURE 60. Circular work table of the R-324 instrument

The aiming at the center of the hole whose position is to be measured can be realized by a number of methods, depending upon the microscope design. The quickest and most accurate is the method of superimposed images, as provided by a superimposed-image head; the noncoincidence of the optical axis of the microscope and the hole axis leads to the appearance of two identical holes in the field of vision of the microscope (Figure 62, a). The machine slides are then displaced till the round holes coincide and the triangular images become star-shaped (Figure 62, b). In this position the optical axis of the microscope and the hole axis are coincident. The higher accuracy of this method is due to the elimination of the influence of the thickness of the reticule marks and to the fact that a shift x of the hole axis relative to the optical axis of the microscope produces a shift 2x between corresponding points on the images.

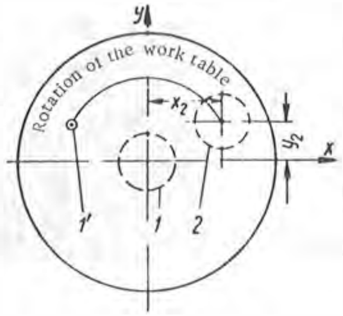


FIGURE 61. Fixing a point on the circular table of the R-324 instrument

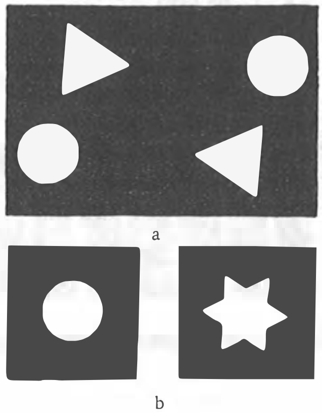


FIGURE 62. Aiming the microscope:

a– noncoincidence of the optical axis of the microscope with the hole axis; b–coincidence of the optical axis of the microscope with the hole axis.

If the microscope is not provided with a superimposed-image head, the measurement is carried out by aiming the cross hairs at the intersections of two mutually perpendicular lines with the hole periphery, and then calculating the coordinates of the hole center (assuming that each coordinate of the center is equal to half the sum of the coordinates of the corresponding intersections of the line with the hole). This method is frequently used, in spite of the larger amount of work involved.

The determination of the actual values of the coordinates is followed by the calculation of the deviations (Δx; Δy)

$$\Delta x = x_{\text{nom}} - x_{\text{act}} \qquad \Delta y = y_{\text{nom}} - y_{\text{act}}$$

where x_{nom} y_{nom} and x_{act} y_{act} are, respectively, the nominal and actual values of the point coordinates.

The accuracy of the coordinate measurements depends on the accuracy of the machine, the positioning and the reading. When a double-image method is used with one of the above-mentioned machines, the measurement error does not exceed 2μ.

Thread Tapping

Watch plates have several threaded holes, used for screwing the watch movement to the case, the dial to the plate and, in some models, the bridges to the plate.

Threads are usually tapped at the last machining operations in order to prevent clogging of the threaded holes during intermediate operations. The machine used for threading is the R-64, whose design is similar to that of the S-3M drilling machine the only difference being that the spindle of the R-54 machine is provided with a friction coupling by means of which it can be rotated in both the clockwise and the anticlockwise sense. Threads of 0.3–1.5 mm diameter can be tapped on this machine. The spindle rotates at 2500 rpm during tapping and at 3600 rpm for unscrewing the tap, the resulting cutting speed is between 2.5 and 12.5 m/min.

A table of cutting speeds for tapping threads in LS63-3 brass and for chasing threads in U7AV steel is given in Appendix 5.

The threading (basic) time is determined from the formula

$$T_{thr} = \frac{L}{s \cdot n_p},$$

where L = tap travel, mm;
s = thread pitch, mm;
n_p = spindle rpm.

The idle (or the unscrewing) time is

$$T_i = T_{thr} \frac{n_p}{n_i},$$

where n_p and n_i are taken from the technical data on the machine.

Example. Let it be required to calculate the machining time on an R-54 machine for threading a hole of 0.7 mm diameter in a plate.

The tap travel is L = 3.2 mm; s = 0.175 mm according to the thread standard; n_p = 2500 rpm, n_i = 3600 rpm, according to the technical data on the machine; whence

$$T_{thr} = \frac{3 \cdot 2}{2500 \cdot 0{,}175} = 0{,}007 \text{ min}$$

$$T_i = T_{thr} \frac{2500}{3600} = 0{,}005 \text{ min};$$

$$T_{mach} = T_{thr} + T_i = 0{,}007 + 0{,}005 = 0{,}012 \text{ min}.$$

The threading allowance in the plate is 20 to 30 % of the nominal thread diameter: the tap drill diameter is 0.4 mm for an M 0.5 thread, 0.55 mm for an M 0.7 thread, and 0.70 mm for an M 1.0 thread.

Figures, inscriptions and trademarks are applied on watch bridges (Figure 63) either by engraving by means of a pantograph or another machine, or by embossing by means of a die. Embossing is the more rapid method but the edges of embossed signs or figures are blurred, and in addition, parts of weak cross section are deformed during embossing. A simple pantograph is used for making inscriptions in small-series production, while in mass production the S-50 machine described earlier and the S-210 machine are used. Fixed inscriptions and signs are automatically engraved in the S-50 machine. The S-210 machine (Figure 64) is more versatile, and is capable of engraving both fixed and varying symbols on flat and cylindrical surfaces.

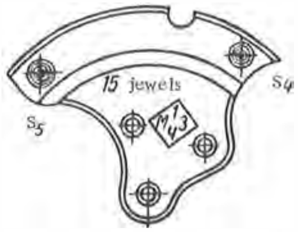


FIGURE 63. Engraved symbols on the train bridge of "Pobeda" watches

The machine has five high-speed spindles with engraving tools mounted at the lower end. The spindles are in the front part of the machine. The spindle block is fastened to the machine base and the work table is fed in the horizontal plane.

The engraving tools engage the work when the spindles are lowered. A master and a stylus are placed below the table. The inscriptions engraved on the parts are reduced in size at a scale of between 1:5 and 1:50 relative to those on the master. The stylus is placed manually along the master groove. The dimensions of the master field are fixed and the lever arms are varied for setting the reduction scale. The engraving tools plunge into the work automatically when the stylus has been lowered into the master groove and leave the parts after the stylus is lifted from the master.

Fixed signs, figures and letters are engraved simultaneously on five parts, while varying symbols are engraved consecutively. Let it thus be required to engrave on five parts the sequence of numbers 21253, 21254, 21255, 21256, 21257. The first four figures 2125 are fixed and the last figure – 3, 4, 5, 6, 7 – is varying. The fixed figures are simultaneously engraved on the five parts, while the last figure is engraved consecutively using a seven-figure template changer which replaces the master.

Technical data, S-210 engraver

Number of spindles	5
Number of parts machined simultaneously	5
Spindle rpm	15,000
Maximum cutting tool diameter, mm	2.5
Maximum cutting depth, mm	1
Maximum field of the master, mm	170 x 65
Copying scales	From 1:5 to 1:50
Maximum dimensions of the machined part (diameter x height), mm	60 x 60
Approximate production rate, pieces/shift	2,500

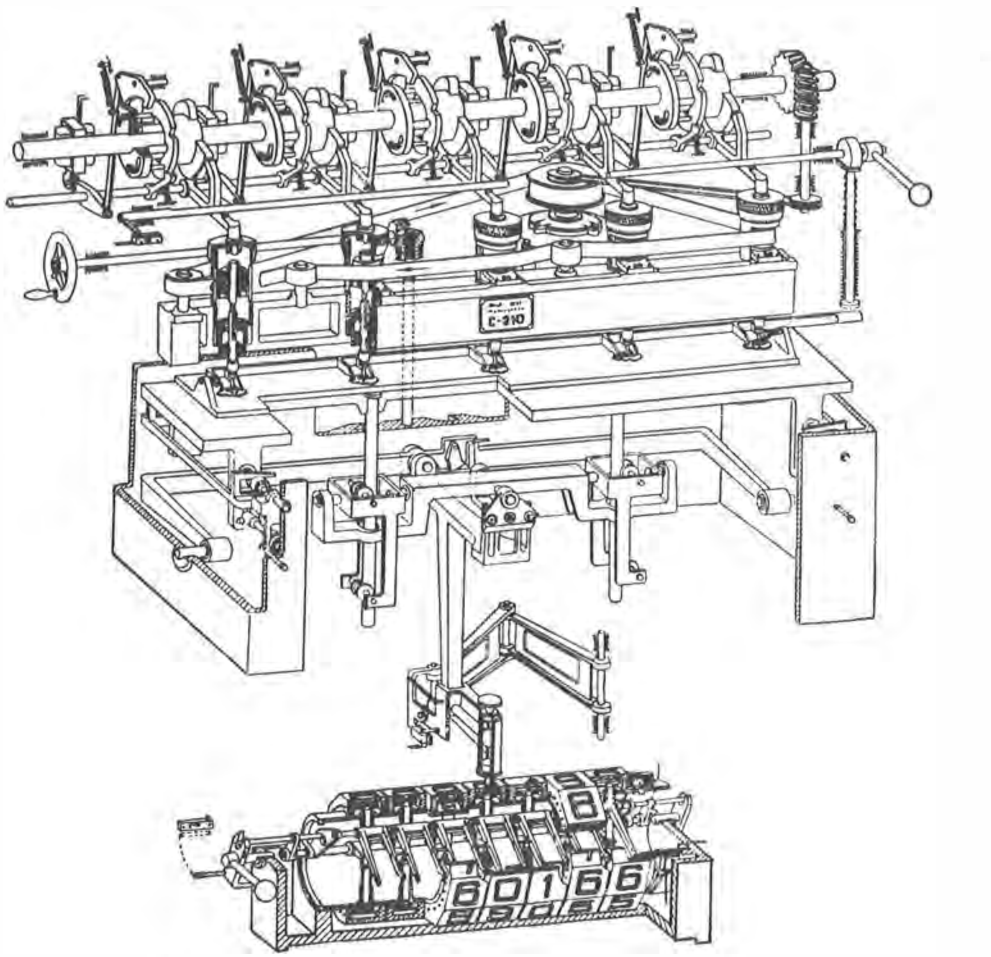


FIGURE 64. Kinematic diagram of the S-210 engraving machine

D e c o r a t i v e t e x t u r i n g (c h a s i n g) or tracing of patterns on the brass parts of watches, is performed on special machines before or after electroplating.

The S-161A seven-spindle semiautomatic chasing machine for engraving rectilinear pattern bands is shown in Figure 65. The spindles revolve at 12,000 rpm and have cutters fastened to their lower end. The part is mounted on a carriage which is displaced underneath the cutters. The part moves in the horizontal plane at an angle to the spindle line. The cutters operate consecutively, and each leaves a pattern band on the part.

One electric motor powers two milling spindles through a belt transmission. The spindle feed is 0.007–0.05 mm/rev, or 200–600 mm/min.

The width of the pattern band produced is determined by the angular offset of the spindles relative to the bed guides, while the width of each separate pattern element depends on the radial offset of the cutting point relative to the axis of revolution.

Because of a small tilt of the spindles, the machining traces have the form of troughs with 0.005 mm maximum depth.

The parts, or sets of parts, to be machined are fastened on a block which is clamped in the carriage. The carriage is moved along the bed guides under the milling cutters by a feed screw. The feed screw is rotated by the electric motor over a worm- reduction gear.

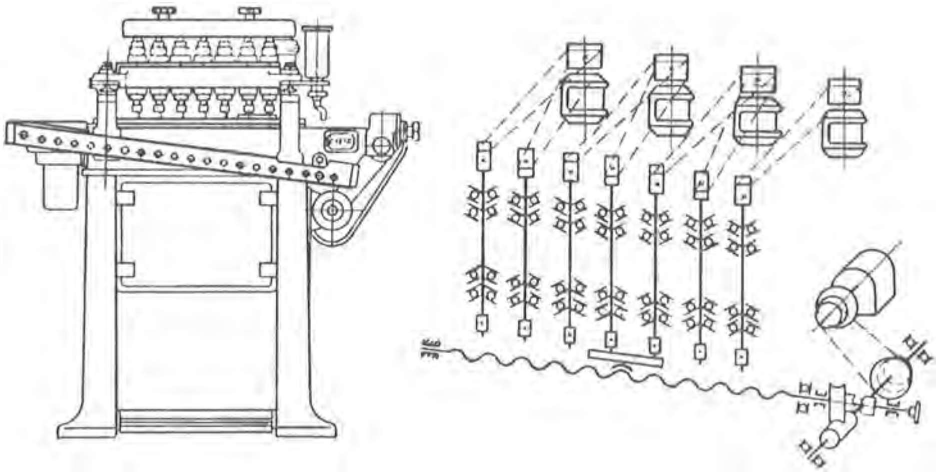


FIGURE 65. General view and kinematic scheme of the S-161A semiautomatic chasing machine

The pattern will be clear and will have a good appearance if the axial play of the spindle does not exceed 0.005 mm, and the radial run-out does not exceed 0.01 mm.

It is recommended to perform the chasing operation prior to electroplating, with the condition that the time interval between the chasing and plating operations shall not exceed 2 hours, as a longer delay would lead to the oxidation and dulling of the surface and to the deterioration of its appearance.

If the chasing is performed after electroplating, it frequently leads to the breaking of the deposited coat and to the appearance of yellow bands, which are centers of corrosion. Corrosion follows after a certain time even if the breaking of the coat is invisible to the naked eye.

Chapter VII

MACHINING THE ESCAPEMENT PARTS

The escapement consists of the lever-escapement assembly and the balance assembly. The lever-escapement assembly includes the escape wheel and pinion, the pallet with pallet stones, the guard pin and the arbor. The balance assembly consists of the balance with staff and screws, the hairspring with collet and stud, and the double roller with impulse pin.

Locally produced escapement parts for watches are at present made of the following materials: escape wheel and pinion, pallet and pallet arbor of U10A high-carbon steel; pallets of synthetic dark-red ruby; and guard pin of LS63-3 brass. The balance rim is made of MNTsS 63-17-18-2 nickel silver which deforms less with time than would a brass rim. Such deformation introduces an error which impairs the watch accuracy.

The hairspring is made of a special nickel alloy of very low temperature coefficient. The temperature coefficient defines the hairspring's capacity to maintain a constant moment with variation of the temperature. The temperature coefficient of the alloy used is 0.3 to 0.5 sec/deg. cent., that is, a variation of 1°C in the ambient temperature produces a variation of the hairspring moment causing an error of 0.3 to 0.5 sec in 24 hours.

THE ESCAPE WHEEL

The escape wheel (Figure 1) must satisfy stric requirements relative to the quality of the surface finish on the working faces of the tooth, accurate geometrical form of the tooth, and minimum run-out with respect to the outside diameter. The tooth profile is obtained by a graphical plotting method. The outer face of the tooth (1) is called the *impulse face*, and the inner face (2) is called *the locking face* (Figure 2).

The impulse face and the locking face are the working faces of the wheel, and they interact with the pallet faces bearing the same names. The surface-finish quality of these faces must be class 11 or 12. In order to facilitate the finish grinding of face (1) and to improve the conditions of the interaction between the wheel and the pallets, a chamfer (3), about 60% of the wheel thickness, is removed from the lateral side of the tooth.

The circular pitch and the impulse-face length must be machined to a tolerance of 0.005–0.01 mm, and the tooth run-out on the outside diameter relative to the pinion journal must not exceed 0.01 mm.

The following operations are involved in the machining of escape wheels: blanking, tooth milling, piercing the central hole, hardening and tempering, face grinding and polishing, and finally grinding and finishing the impulse and locking faces.

The wheel is blanked out of a polished steel strip (Figure 3) by a die (see Figure 21, Chapter III). The teeth are milled in the S-109 seven-spindle semiautomatic milling machine (Figure 4).

FIGURE 1. Escape wheel

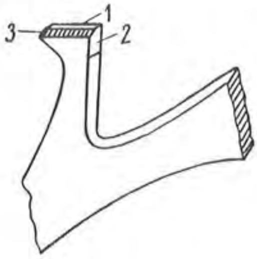


FIGURE 2. Escape-wheel tooth: 1–impulse face; 2–locking face 3–chamfer.

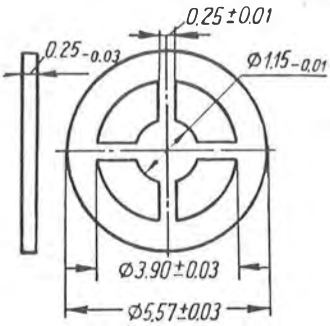


FIGURE 3. Escape-wheel blank

The wheel blanks are copper-plated before the teeth are milled. The copper layer on the two surfaces acts as a cushion between the wheels and improves the cutting conditions. It has been established in practice that the copper plating improves the surface-finish quality of the milled wheels by one class (to class 7) and increases the life of the milling cutter by 50 to 100% (up to 350 min). The blanks are stacked on a correspondingly shaped mandrel (Figure 5) in stacks of 50 pieces and mounted between the centers of the dividing head of the machine.

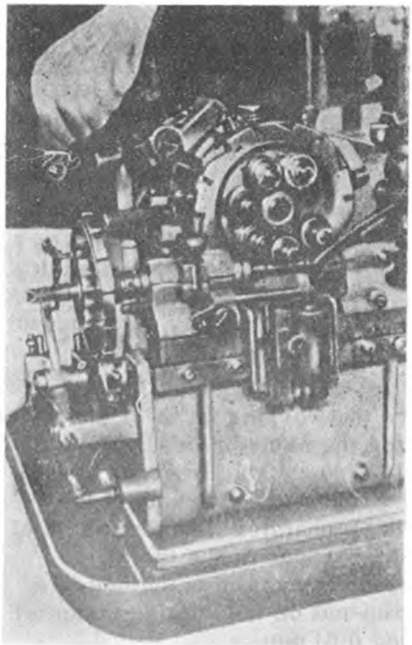


FIGURE 4. S-109 machine for milling escape-wheel teeth

Each of the spindles on the S-109 machine carries a fine-tooth formed cutter, whose dimensions and tooth form are given in Figure 6. Figure 7 gives the sequence of the tooth-forming operations.

The milling allowance for the escape wheel of "Pobeda" watches is 0.15 mm on the diameter, and the tolerance is 0.02–0.03 mm. The tooth profile is rough-milled in the first three operations, and finish-milled in the next three*. The sixth operation consists in the finish milling of the tooth heel and the impulse face.

No burrs are formed on the tooth heel in these milling operations. Each cutter mills all the teeth, after which the spindle barrel is indexed.

* The seventh spindle of the machine is free.

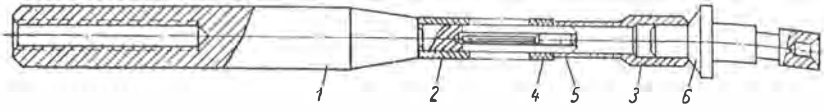


FIGURE 5. Mandrel for milling escape-wheel teeth:

1–mandrel; 2–sleeve; 3–clamping piece; 4–washer; 5–insert; 6–holder.

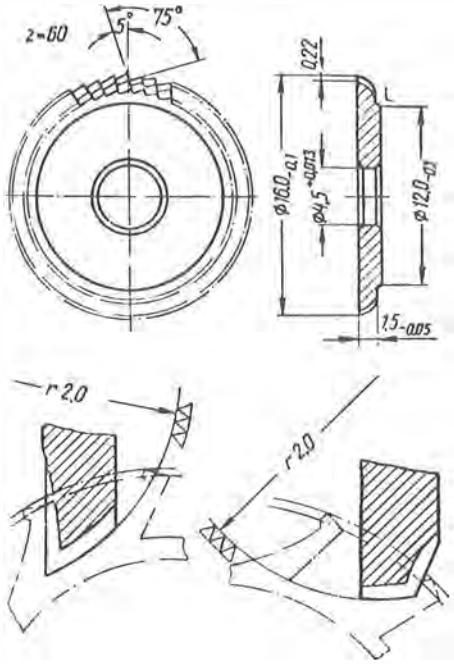


FIGURE 6. Fine-tooth formed cutter

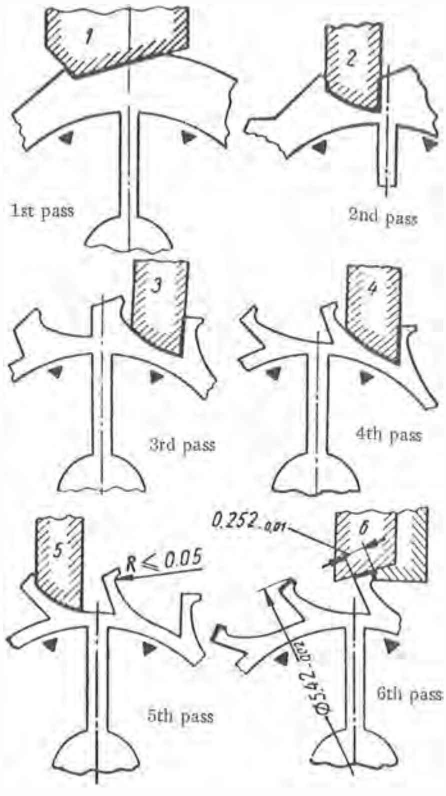


FIGURE 7. Sequence of operations in milling escape-wheel teeth

The kinematic scheme of the S-109 machine is given in Figure 8.

The electric motor rotates the driveshaft I (Figure 8), and, via a series of belt transmissions, the milling spindle (1) and the camshaft II. The camshaft rotates the dividing head (2) and moves the carriage (3). The machine is equipped with a device for the automatic switchover of the spindle barrel. Each spindle has an adjusting device for positioning the spindle relative to the mandrel carrying the blanks.

Technical data, S-109 machine

Milling length, mm	5—30
Maximum axial spindle travel, mm	10
Maximum diameter of milled wheel, mm ..	15
Spindle speed, rpm	1770
Milling speed, m/min	90
Camshaft speeds, rpm	4.2; 3; 2.1
Feed per cutter revolution, mm	0.008—0.086
Electric motor	0.5 kw, 1500 rpm
Production rate	650—750 wheels/shift

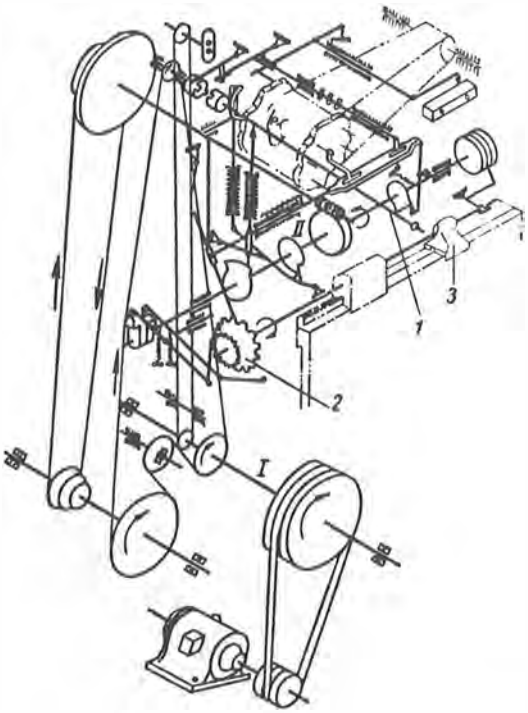


FIGURE 8. Kinematic scheme of the S-109 machine

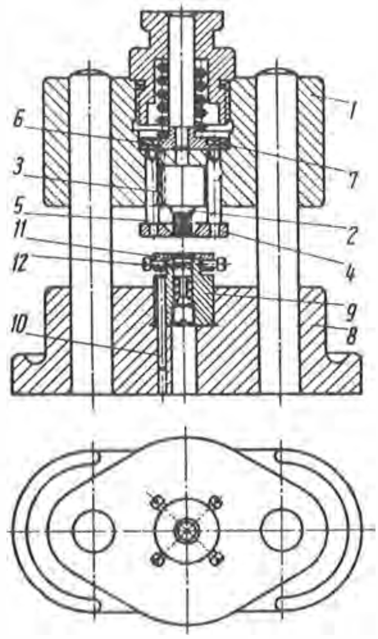


FIGURE 9. General view of die for blanking escape-wheel teeth:

1—upper shoe; 2—punch; 3—key; 4—stripper; 5—stripper pin; 6—screw; 7—spring plate; 8—lower shoe; 9—die; 10—key; 11—nest; 12—knockout.

Some watch plants blank out the wheel teeth so that the milling becomes unnecessary. Although this method is more productive, the design of such a die is complex (Figure 9), and the service life of punch and die is short.

The punch (2) is tightly fitted into the upper shoe (1). The key (3) locks the punch teeth in a fixed position. The stripper (4) is fastened by means of the three stripper pins (5) and the screws (6) to the spring plate (7).

The die (9) is tightly mounted in the lower shoe (8). The key (10) locks the die in a fixed position. The nest (11) positions the wheel blank relative to the die. The knockout (12) is mounted inside the die.

The working part of the punch (2) (Figure 10, a) is manufactured with an allowance for grinding and polishing the teeth. The die (9) is broached by the punch. Wheel blanks for this die (Figure 3) are blanked to a diameter of $5.80^{\pm 0.03}$, while wheel blanks which are to be milled are blanked to $5.57^{\pm 0.03}$.

The knockout (12) (Figure 9) consists of a base and a ring with the working contour which is a close-running fit in the die (Figure 10, b).

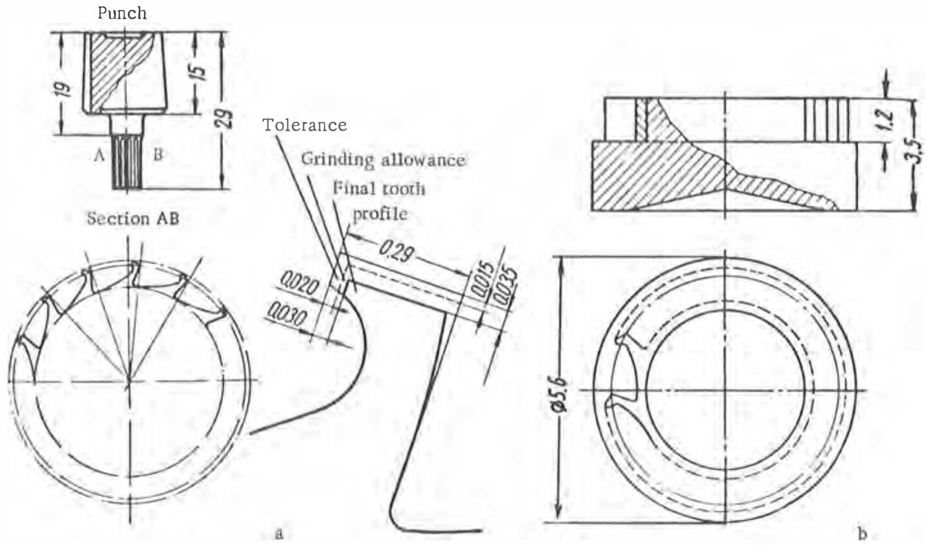


FIGURE 10. Parts of the die for blanking the escape wheel: a–punch; b–knockout (compound).

The central hole in the escape wheel (Figure 11) is pierced by a punch. The wheel is located according to the outside diameter of the teeth. The tolerance on the hole diameter is 0.005 mm and the permissible run-out on the outside diameter is 0.015 mm. The piercing is followed by hardening and tempering to $R_c = 53-55$, after which the wheel is fed to the S-15 machine for surface grinding and polishing (see Chapter IX). The impulse face and locking face are finish-machined in the S-125A and S-126A machines.

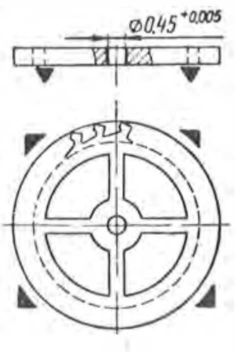


FIGURE 11. Piercing the central hole of the escape wheel

The impulse face is ground on the S-125A machine (Figure 12) and the wheel is located by the central hole. One escape wheel is held on the mandrel. The wheel diameter has an allowance of 0.03 mm for grinding. The impulse face and the side chamfer are ground in one chucking (Figure 13). The diameter tolerance is 0.01 mm, and the permissible run-out is 0.005 mm. The impulse face is ground by abrasive wheels of grain size 240 at a speed of 2–12 m/sec.

The kinematic diagram of the S-125A machine is given in Figure 14.

The two-step pulley on the electric motor shaft drives the driveshaft I through round belts. Three three-step pulleys are mounted on the driveshaft; they drive the longitudinal and lateral grinding quills through round belts, and the camshaft II through a worm and wheel. The camshaft carries the cam (7) which controls the dividing head (10), the one-tooth pinion controlling the automatic switch-off of the machine, and the crank disk (1) which rocks the spindle (3) through bar (2). The grinding wheel, mounted on the longitudinal quill (6), grinds the impulse face, and the wheel mounted on the transversal quill (11) grinds the chamfers.

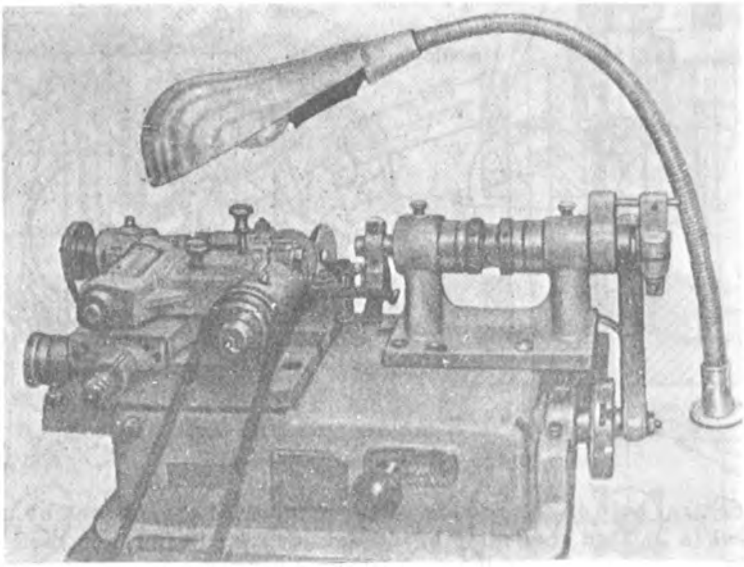


FIGURE 12. General view of the S-125A machine

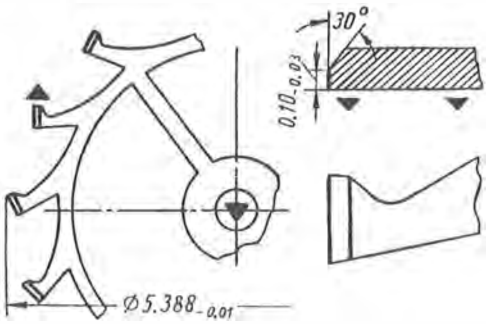


FIGURE 13. Grinding the impulse face and chamfer on the escape-wheel tooth

The escape wheel is fed under the grinding wheels on the two spindles by the rocking of the dividing head (10), mounted on the spindle head.

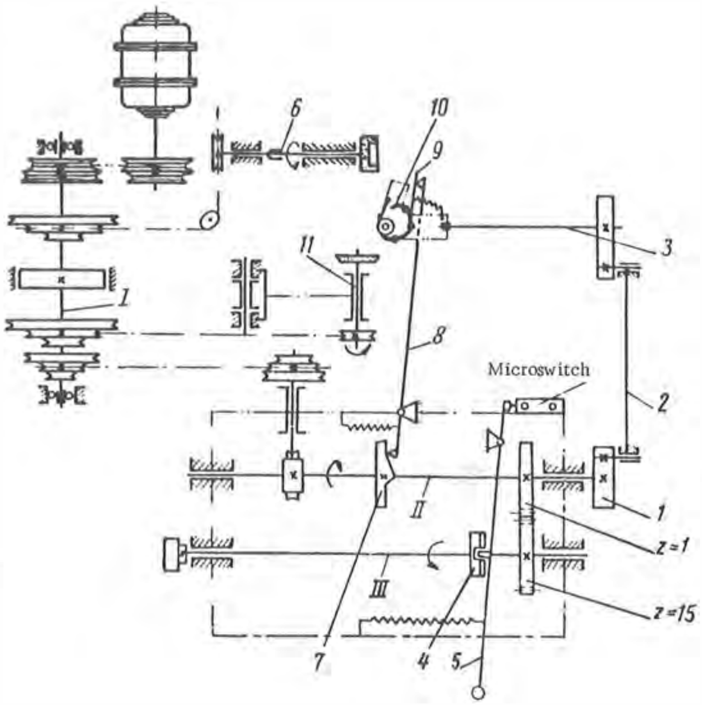


FIGURE 14. Kinematic diagram of the S-125A machine

The dividing head is indexed one division (one wheel tooth) upon each revolution of cam (7) through levers (8) and (9). At the end of the machining cycle, that is, when the one-tooth pinion z_1 has rotated the wheel z_{15} one revolution, the stop (4) fitted on shaft III moves the lever (5) to the right, and the microswitch switches off the electric motor. This stops the machine.

Technical data, S-125A machine

Maximum diameter of the wheel machined, mm	15
Number of teeth on the wheel machined	15
Number of camshaft speeds	6
Range of camshaft speeds, rpm	24.7—32
Range of spindle speeds, rpm	1150—4420
Electric motor	0.25 kw, 1500 rpm
Time per cycle, sec	6.8—36.4

The impulse face and the locking face are accurately ground on the S-126A machine (Figure 15). The wheel is again located according to the central hole.

The-surface finish quality of the two faces must be not poorer than class 12. One wheel is held on the mandrel at a time.

An allowance of 0.01 mm is left on the diameter for the finish grinding. The two faces are ground simultaneously by AZ* abrasive wheels. The wheel shape is shown in Figure 16. No burrs are formed on the tooth edges with this wheel arrangement. The diameter tolerance is 0.01 mm and the permissible run-out is 0.005 mm.

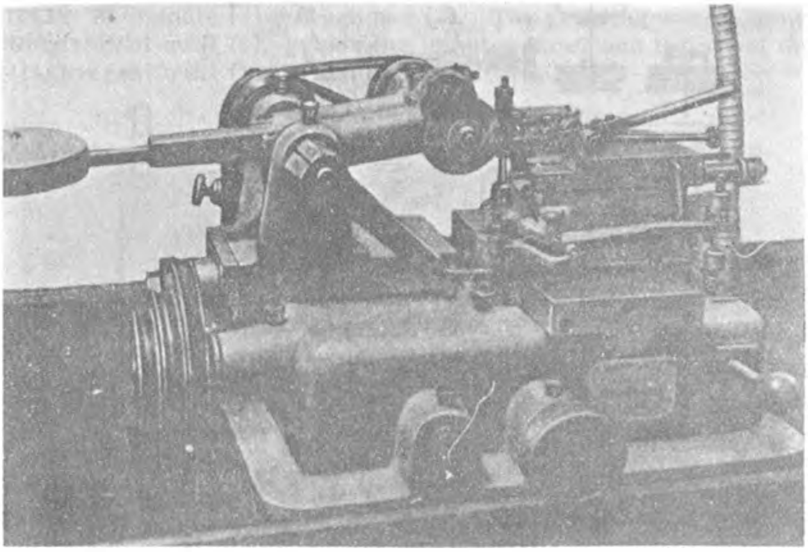


FIGURE 15. General view of the S-126A machine

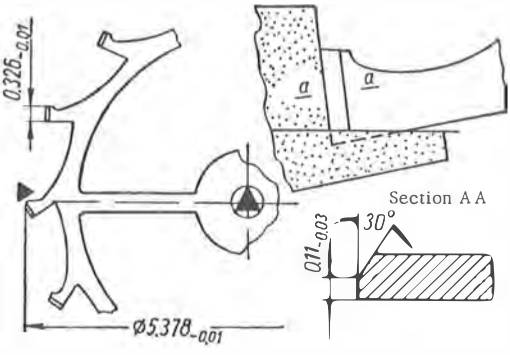


FIGURE 16. Finish grinding of the impulse face and the locking face of escape-wheel teeth

The kinematic diagram of the S-126A machine is given in Figure 17.

The two-step pulley on the electric motor drives the countershaft I by means of round belts. Three-step pulleys are mounted on the countershaft driving the quill through round belts, and the camshaft II through a worm and wheel. The camshaft carries the one-tooth wheel z_1, which controls

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* [AZ is an abbreviation for the Russian AlmazoZamenitel' - diamond substitute.]

the automatic stoppage of the machine, and the cam (1), which rocks the quill, that is, moves the grinding wheel toward and way from the wheel being machined.

The quill which carries the AZ grinding wheels is periodically lowered under the action of rocking levers mounted on the auxiliary shaft III, and grinds the impulse face and the locking face simultaneously (Figure 16).

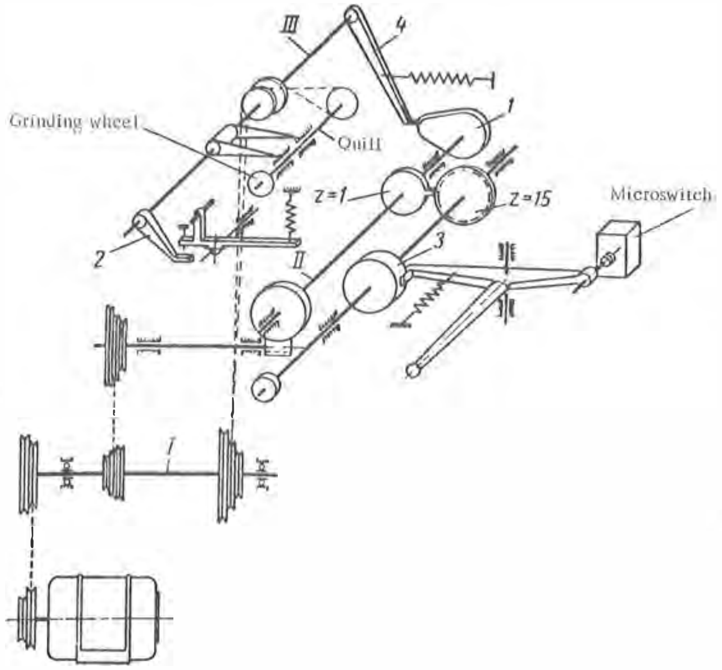


FIGURE 17. Kinematic diagram of the S-126A machine

Lever (2), mounted on the auxiliary shaft, controls the dividing head. It is indexed a given angle by the lever (4) and cam (1). At the end of the machining cycle the one-tooth wheel z_1 has rotated the gear wheel z_{15} one full revolution, as was the case with the S-125A machine, and the stop (3) stops the machine.

Technical data, S-126A machine

Maximum diameter of the wheel machined, mm	15
Number of teeth on the wheel machined	15
Number of camshaft speeds	6
Range of camshaft speeds, rpm	18.2—85.5
Range of spindle speeds, rpm	1150—4420
Electric motor	0.25 kw. 1500 rpm
Time per cycle, sec	10.5—49.5

Random inspection is carried out during each of the operations involved in the machining of the escape wheel. In addition, the finished product is inspected 100% for the basic parameters. The outside diameter, the tooth profile and the circular pitch are inspected on a profile projector.

The run-out is inspected on an indicator instrument in a manner similar to that in which modular gear wheels are inspected. The surface-finish quality is inspected visually under plant conditions using a magnifying glass with a magnification of 5× or 10×, or a microscope with a magnification of 16 – 32×.

THE PALLET LEVER AND THE GUARD PIN

In the movements of pocket and wristwatches the pallet lever (Figure 18) receives impulses from the escape wheel through the interaction of the pallets (pallet stones) with the wheel teeth, and transmits the impulses to the balance through the interaction of the pallet fork and the impulse pin on the double roller (Figure 19).

FIGURE 18. Pallet lever

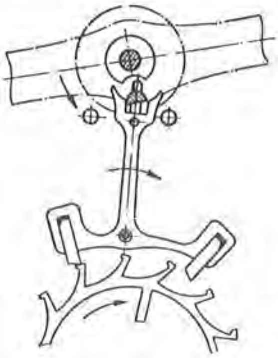


FIGURE 19. Impulse transmission

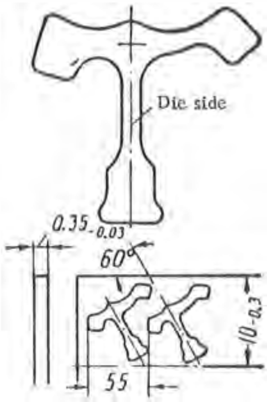


FIGURE 20. Strip layout for blanking the pallet lever

To ensure correct escapement – balance interaction, the slots for the pallet stones and the hole for the impulse pin must not only be of accurate width, but must also be correctly positioned relative to the axis of the fork slot.

These slots are machined on special machines. The blank (Figure 20) is punched out from a strip by a compound die with simultaneous contour shaving (first operation).

The pallet lever has a complex asymmetric contour and the clearances between punch and die must be perfectly uniform. In order to obtain die working surfaces of quality class 10 at least, one uses a sectional die (Figure 21, a). The still soft punch is broached in the die set by the die, and finish-ground in place after heat treatment. The die is of the sectional type and is made of three parts. The die entrance has a 0.05 mm radius and is ground to a class-10 finish. The die is mounted in a ring (Figure 21,b),

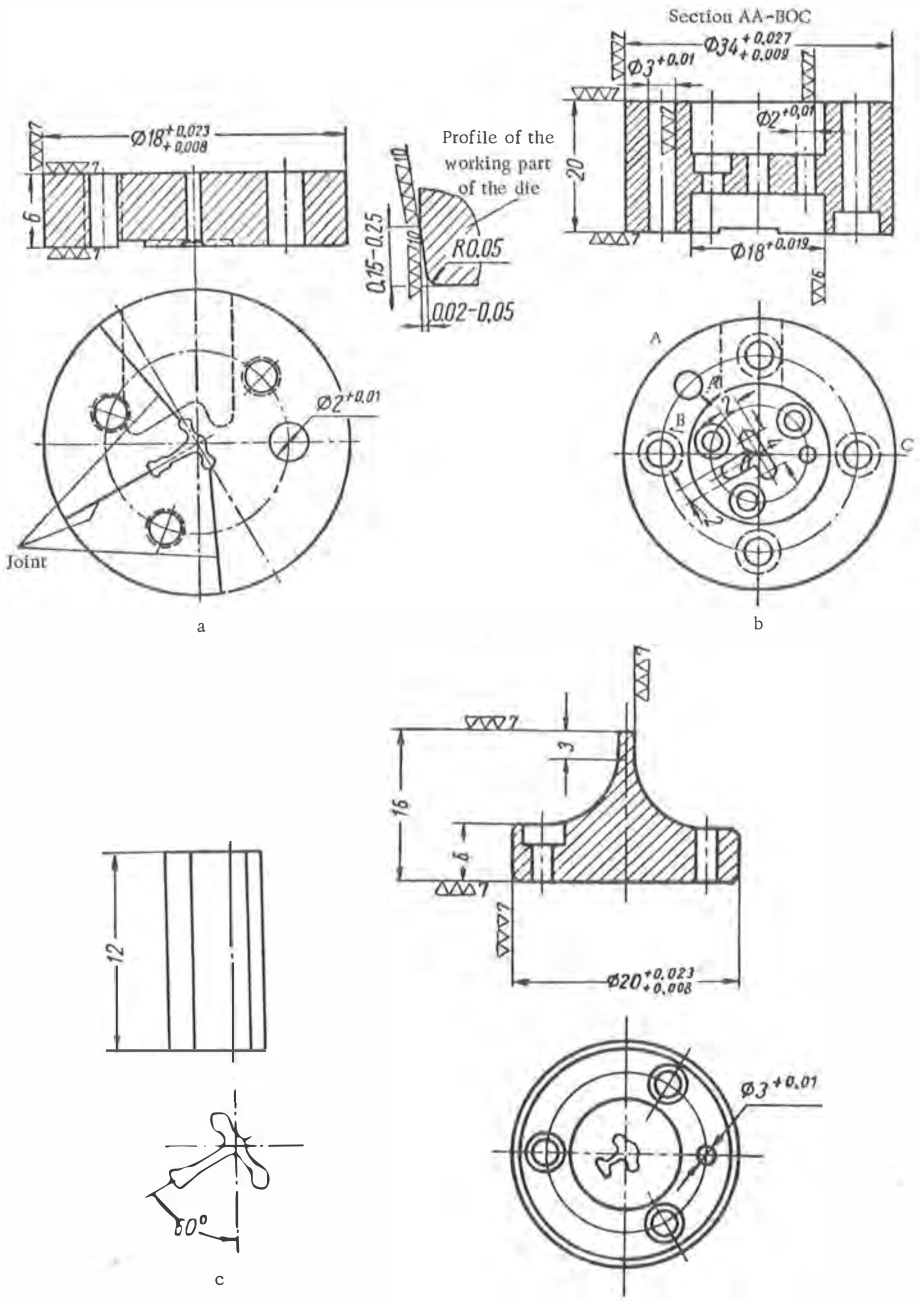


FIGURE 21. Parts of the die for blanking and shaving the pallet lever:
a–die (sectional); b–die-mounting ring; c–upper knockout; d–contour punch.

and the ring is held in the upper shoe of the die set. The knockout (Figure 21, c), whose profile is a close-running fit in the die profile passes through the die and ring. The design of the punch, which is mounted in the lower shoe, is shown in Figure 21, d. The punch profile is ground according to the die profile with a clearance of 0.01 mm on each side at the expense of the punch.

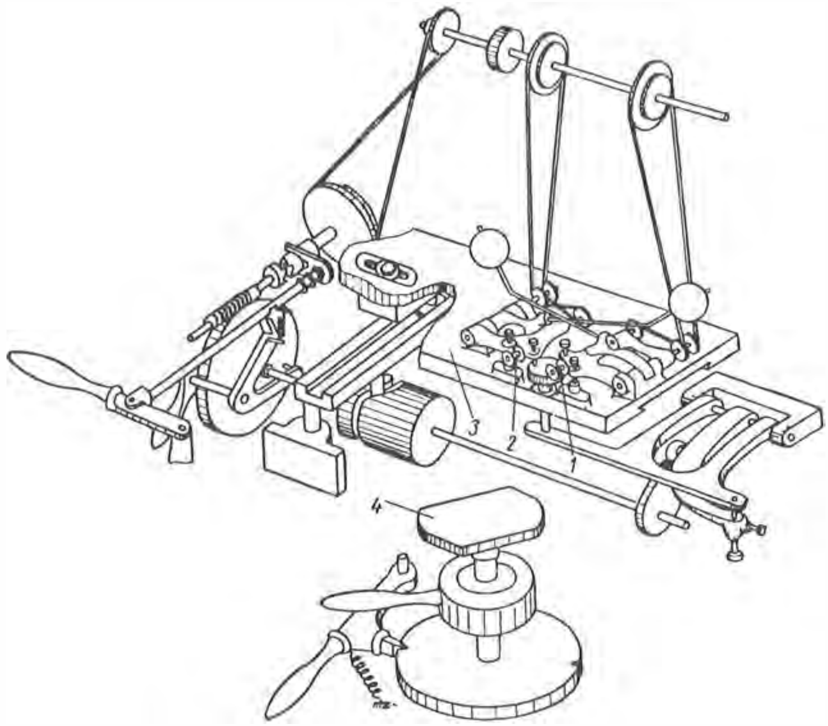


FIGURE 22. S-45 two-spindle horizontal milling machine

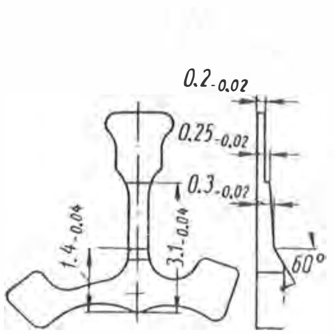


FIGURE 23. Milling two steps

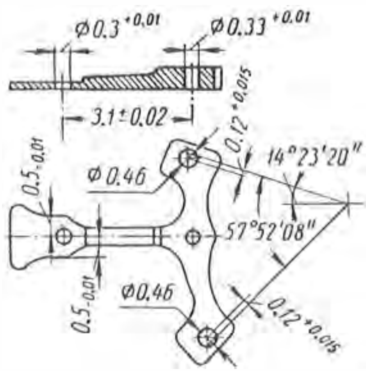


FIGURE 24. Piercing four holes

The blanked pallet lever is then transferred to the S-45 two-spindle machine (Figure 22) where the two steps are milled (second operation) (Figure 23). The machine is equipped with a rotary table (4) (Figure 22) on which are mounted two five-place chucking fixtures with contoured plates to take the pallet-lever blanks. New blanks are loaded in one of the fixtures while those in the other are being milled. The pallet-lever faces are milled consecutively by the cutters in the first and second spindles. The worktable is fixed during milling, while the cutter table (3) moves.

Technical data, S-45 machine

Spindle speed, rpm	2200--4000
Worktable diameter, mm	160
Production rate, parts/shift	4000
Electric motor	0.75 kw, 1440 rpm

The milling of the lever steps is followed by the piercing of two circular holes for the arbor and the guard pin, and two contoured holes at the places where the pallet slots are to be situated (third operation) (Figure 24). The piercing is performed in the Sh-04 die. The location of the contoured holes is so chosen that recesses of 0.03 – 0.05 mm depth remain on the outer side of each slot after the slots are milled. The pallet stone is thus caused to fit closely the inner side of the slot (Figure 25, a). Figure 25, b shows the position of a pallet stone in a slot without a recess. The correct disposition of the four holes relative to the pallet contour is achieved by piercing them simultaneously. The die (Figure 26, d) used must be accurate.

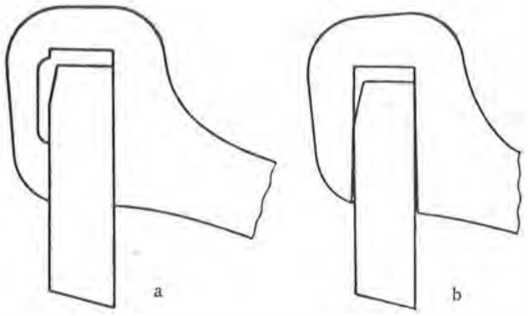


FIGURE 25. Shape of the pallet-stone slots in the pallet lever

The punches (Figure 26, a), the punch holder, and the stripper (Figure 26, b and c) are mounted in a ring.

The next (fourth) operation is the countersinking of the holes, performed on the S-3 m machine. The fifth and sixth operations are the milling of the fork and the stone slots (Figures 27 and 28), on the S-47 and S-48 machines, respectively. The production rate of the S-48 machine (Figure 29), which uses a slotting milling cutter for milling the pallet-stone slots, is 3000 parts per shift. The following (seventh) operation is the calibration of the conical hole (Figure 30) to take the conical portion of the arbor. This operation is performed on a hand press.

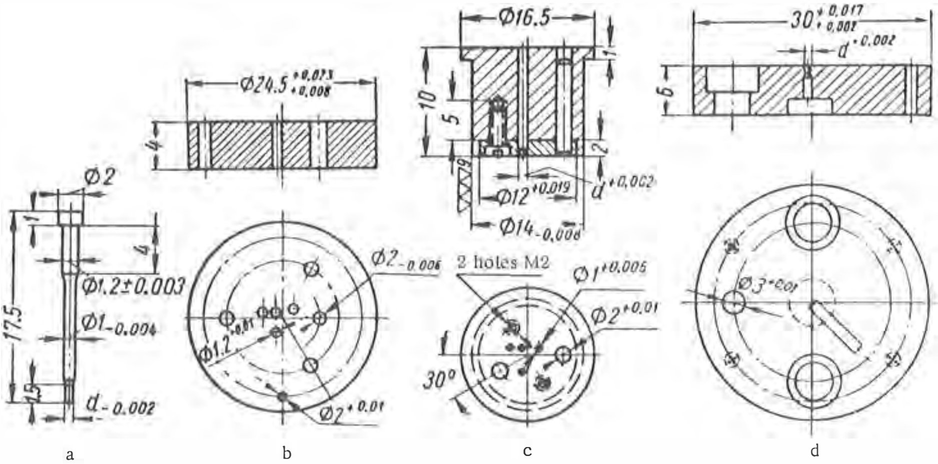


FIGURE 26. Shaving die for the four holes in the pallet

a–punch; b–punch holder; c–stripper with insert; d–die.

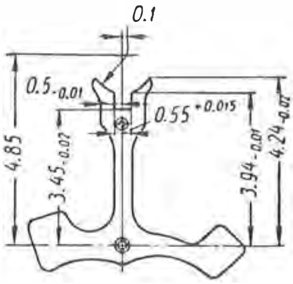


FIGURE 27. Milling the fork and the impulse pin slot

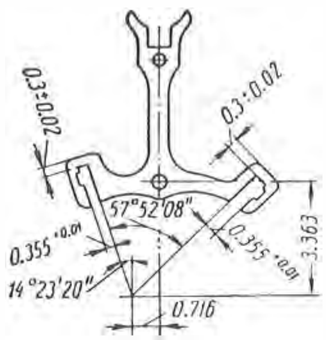


FIGURE 28. Milling the pallet-stone slots

The pallet lever is then hardened and tempered to R_c = 53 — 55 (eighth operation), after which the impulse pin slot curves are polished (ninth operation) (Figure 32) on the S-131 machine (Figure 31).

An oval shape is given the slot walls in order to reduce the surface of contact with the impulse pin and to increase the surface-finish quality from class 7 to class 10–11.

The polishing operation is conducted as follows. The pallet lever is clamped in a fixture in the chuck (1) (Figure 31). The spindle with the AZ polishing wheel is mounted on the slide (2). The link system (3) imparts an oscillating motion to the chuck carrying the pallet lever. The wheel penetrates into the slot opening and rounds off the sharp edges. The right-hand upper edge and the left-hand lower edge are first rounded off simultaneously, and in the next oscillation the left-hand upper edge and the right-hand lower edge are rounded-off simultaneously.

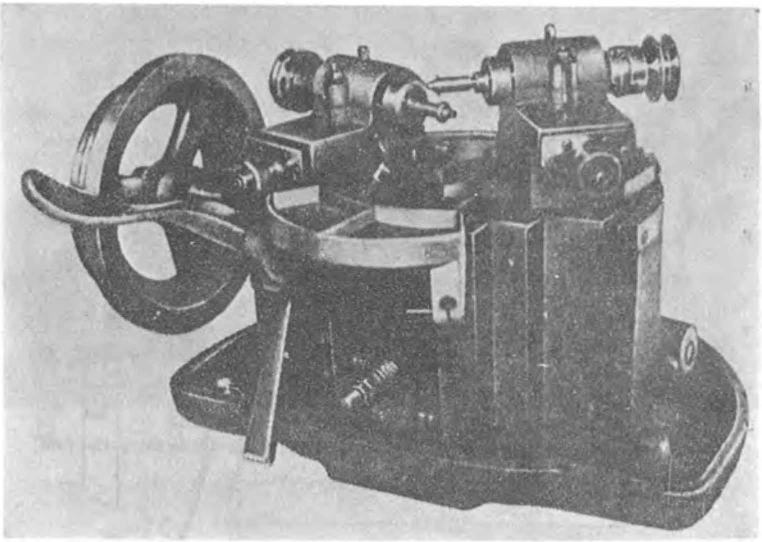


FIGURE 29. S-48 machine for milling the pallet-stone slots in the pallet lever

The guard pin (Figure 35) has a complex configuration. The manufacturing process consists in turning blanks on 1A10P automatic machines and contour-blanking in a bench hand press. The ring (2) which serves for holding the blank is put on the die (1) (Figure 36). The punch (3) blanks the guard pin, which passes through the die and falls into the trough (4). Chips and scrap are removed from the press by a jet of air. The guide cleat (5) positions the punch (3) relative to the die (1).

The pallet lever with the polished slots is face-ground and face-polished in the S-15 machine (tenth operation) (Figure 33).

In addition to the above-listed ten basic operations there are deburring operations, chucking for face grinding and polishing, and subsequent unchucking, washing, etc. The pallet lever is subjected to a total of about 40 different operations.

Each operation is followed by a random inspection, and the basic parameters of every pallet lever are inspected after the final operation. The mutual disposition of slots, holes and contour is inspected by means of a profile projector. The pallet lever is laid on the projector table, and the glass drawing of the pallet lever (greatly enlarged) is placed on the screen. Figure 34 is a drawing of the pallet lever giving the tolerances. The surface quality is inspected visually by means of a 5X – 10X magnifying glass. A microscope with a magnification of 16X to 32X is used in dubious cases.

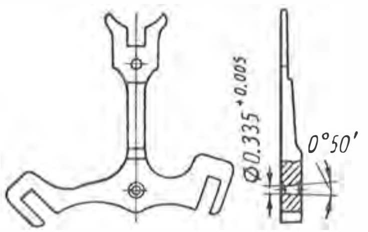


FIGURE 30. Calibration of the arbor hole in a die

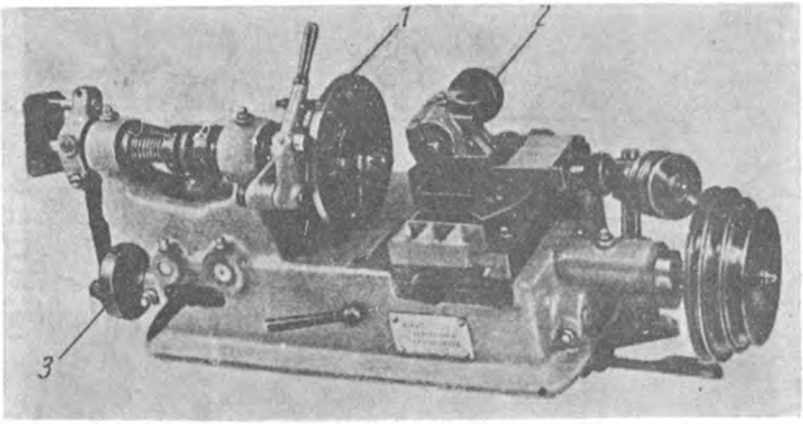


FIGURE 31. S-131 machine for polishing the impulse pin slot in the pallet fork

Technical data, S-131 machine

Maximum angle of oscillation of the chuck, degrees	60
Maximum polishing radius, mm	1
Axial travel of the work spindle, mm	8
Polishing-wheel diameter, mm	40–50
Polishing-wheel speed, rpm	3500
Cross travel of the polishing-wheel head, mm	0.18
Longitudinal travel of the polishing-wheel head, mm	10
Production rate, parts/shift	2500

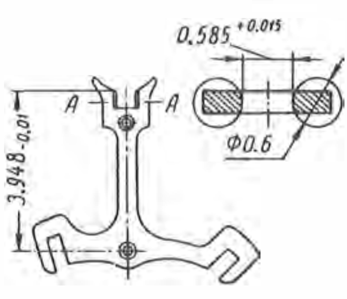


FIGURE 32. Polishing the impulse pin slot (fork)

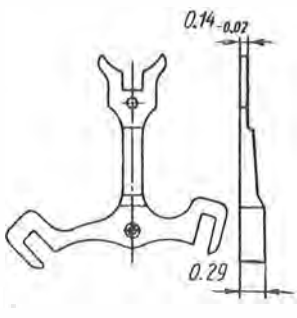


FIGURE 33. Grinding and polishing of the upper face

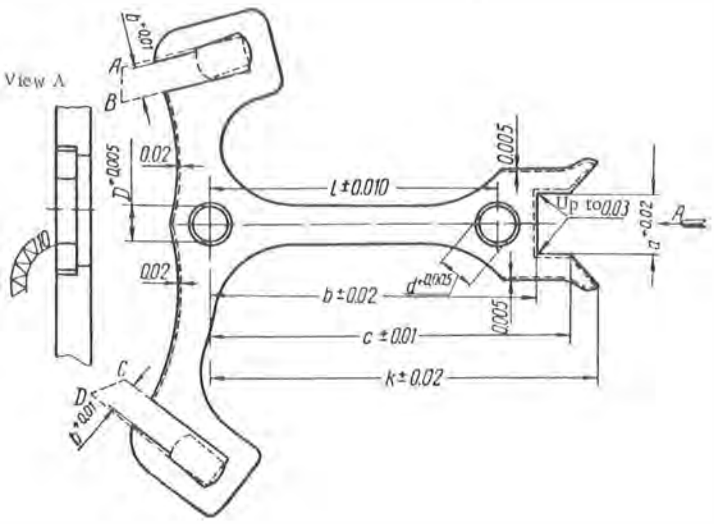


FIGURE 34. Drawing of a wristwatch pallet lever for a profile projector

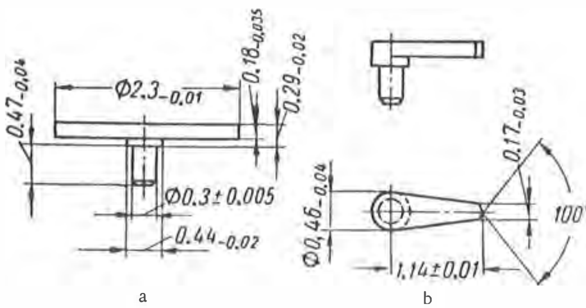


FIGURE 35. Guard pin:

a–blank; b–after contouring.

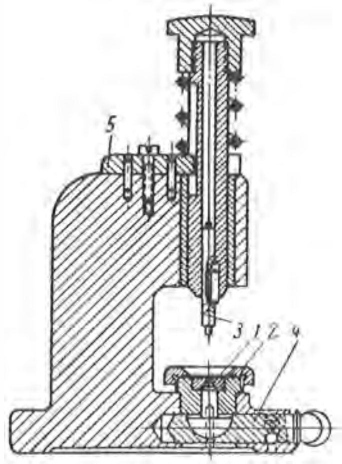


FIGURE 36. Bench press for blanking guard pins

The balance assembly (balance-hairspring, Figure 37) is the most critical part in the watch movement.

The balance and hairspring in pocket- and wristwatches perform 18,000 half-oscillations in an hour, or 432,000 half-oscillations in 24 hours. Assuming that the watch accuracy is 30 sec per day, the relative daily error will be $\frac{30}{86,400} \times 100\% = 0.035\%$.

The hairspring works continuously for many years with reversing cyclic load, and must preserve its elasticity under these conditions.

The period of the balance oscillations is expressed by the formula

$$T = 2\pi \sqrt{\frac{J}{k}},$$

where T = period, sec;
J = moment of inertia of the balance, g. mm. sec^2;
k = moment of the hairspring per 1 radian of torsioning, in g. mm

In turn,

$$J = mr^2,$$

where m = the balance mass;
r = the radius of gyration of the balance.

The most advantageous arrangement is a small mass and a large radius of gyration. To achieve this, the dimensions of the outer balance rim are made as large as possible, and the main metal mass is concentrated in this rim. The moment of inertia of the rim with its screws is roughly 90% of the total moment of inertia of the balance with staff and central arm. Figure 38 is a drawing of the balance rim of "Pobeda" wristwatches. Its outer diameter is 9.52 mm, and its thickness 0.36 mm. Sixteen compensation screws are placed about its circumference. The number of screws varies between 12 and 18 in other watch brands. A larger number of screws increases the balance compensation, but also proportionally increases the work expenditure on balance manufacture. A balance with a large number of screws (16–18) is therefore used in very accurate watches (10–30 sec error in 24 hours).

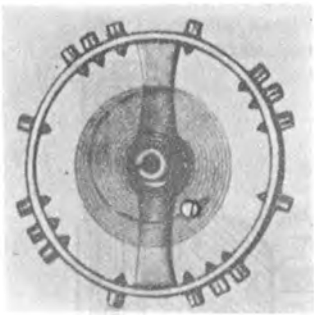
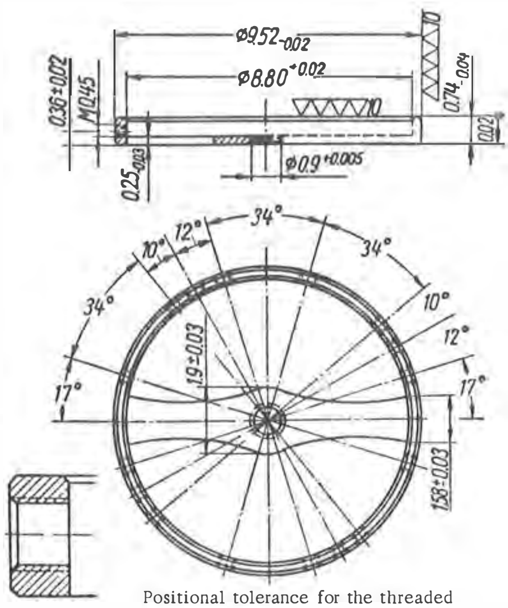


FIGURE 37. Balance with hairspring

In alarm clocks, which have a daily error of 1.5–2.5 min, the balance has no screws. If the moment of inertia J, is to be constant, the radius of gyration r must be held within narrow limits. The balance rim is therefore manufactured with 0.01–0.02 mm tolerance on the inner and outer diameters and the eccentricity between the rim diameters does not exceed 0.02 mm. Good balance compensation requires a constant moment of inertia and the coincidence of the center of gravity and the geometrical center of the balance rim. The main factor causing noncoincidence of the two centers is the run-out of the rim relative to the axis of revolution. Accordingly, the total run-out of the balance outside and inside diameters must not exceed 0.02 mm.

The balance of "Pobeda" watches is blanked from strip material in a combination die (first operation, Figure 39).

Blanking and shaving are followed by stress relief (second operation). The purpose of stress-relieving heat treatment (used in watch production for brass and nickel-silver parts) is to eliminate the further deformation of parts after mechanical treatment. The hardness of the metal is not impaired by this process.



Positional tolerance for the threaded holes: ± 0°30'

FIGURE 38. Balance of the "Pobeda" wristwatch

Watch parts are stress-relieved in the PN-316 shaft furnace, whose production rate is up to 100 kg/hour. The maximum furnace temperature is 650°C, the power consumed 24 kw, the internal diameter 400 mm, and the height 500 mm. The stress-relieving conditions for nickel-silver are: heating for two hours at 340–360° followed by air cooling. The furnace is charged with 5000–20,000 parts simultaneously.

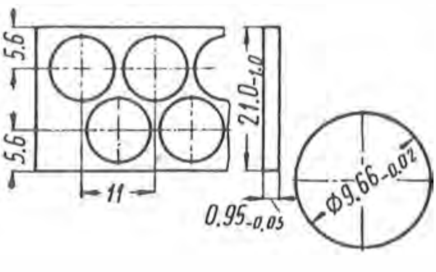


FIGURE 39. Preparing the blank

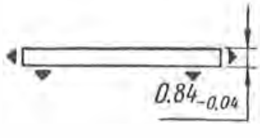


FIGURE 40. Facing

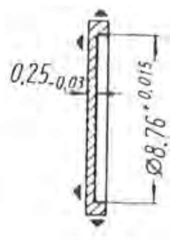


FIGURE 41. Recessing from the die side

Some shaft furnaces have forced air circulation to achieve a more uniform heating of the parts.

If no shaft furnaces are available, stress relieving can be carried out in an oil bath. The oil-bath process is more expensive, however, because a considerable quantity of oil and washing compound is consumed. The capacity of a bath is usually one half or one third that of a shaft furnace.

The stress-relieved balance blanks are then washed according to the standards (third operation).

The blank is faced (fourth operation, Figure 40) in automatic machines with magazine loading, and then recessed (fifth operation, Figure 41). This operation removes a layer of metal and provides a holding surface for the following operation.

The sixth operation (Figure 42), performed on the Sh-06 hydraulic press, consists in piercing the windows, piercing the central hole and shaving the outer and inner rim diameters. The run-out of the outer and inner diameters relative to the central hole after this operation must not exceed 0.02 mm.

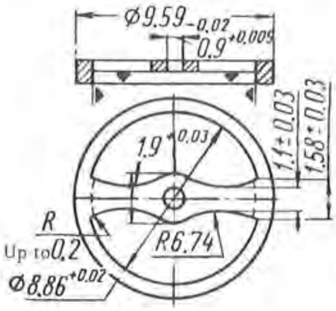


FIGURE 42. Piercing the windows and the central hole, and shaving the rim

FIGURE 43. Countersinking the central hole

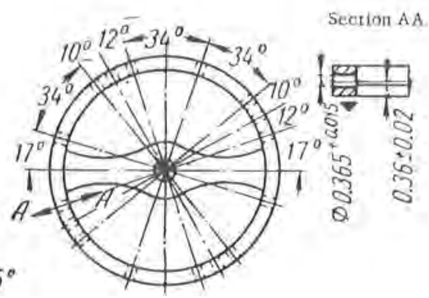


FIGURE 44. Drilling 16 holes

The central hole is then countersunk (seventh operation, Figure 43), and 16 radial holes of 0.365 mm diameter are drilled in a semiautomatic horizontal drilling machine (eighth operation, Figure 44). All the holes must be drilled at the same distance from the lower face.

Next, the upper face of the rim is faced and a chamfer turned in a special semiautomatic machine (ninth operation, Figure 45). The nonparalleleity of the faces must not exceed 0.015 mm.

The outer diameter of the balance rim is then turned on special semiautomatic machines in order to eliminate run-out and to remove burrs resulting from the drilling of the screw holes (tenth operation, Figure 46). The maximum permissible run-out is 0.015 mm.

The rim holes are next tapped on the S-72 machine with manual headstock feed (eleventh operation, Figure 47).

The last operation is the polishing of the upper face of the balance which is done on the S-122 machine (twelfth operation, Figure 48).

The T-229 semiautomatic machine (Figure 49) was especially designed for the machining of the balance rim, with the twin aims of increasing the process accuracy and reducing the number of operations.

The machine is equipped with five tool slides. The following operations are performed in one chucking of the balance: turning the outer and inner diameters, facing, turning two chamfers, and boring a hole. The spindle revolves at 30,000 rpm, corresponding to a cutting speed of 900 m/min.

Carbide-tipped and ruby-tipped tools are used. The circular and face run-out tolerances are narrowed to 0.01 mm, and the surface quality is improved to class 11. The time taken by one cycle varies between 10 and 20 sec. The machine performs operations 9, 10 and 12 of the above indicated.

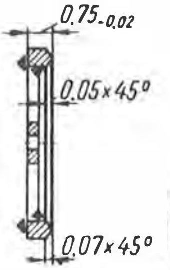


FIGURE 45. Facing the upper face and chamfering

FIGURE 46. Turning the outer diameter

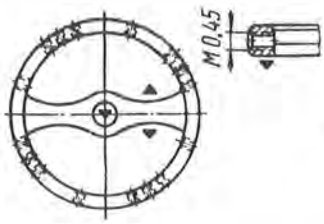


FIGURE 47. Tapping the 16 holes

FIGURE 48. Polishing the upper face

The balance is located and positioned on a mandrel according to the inner rim diameter at a height equal to the central arm thickness.

In addition to the improvement of the machining methods, attempts are being made of late in watch plants to manufacture the balance rim by swaging. The balance of "Zvezda" watches is blanked in a crank press from a strip, with preliminary drawing of the hub (Figure 50, a).

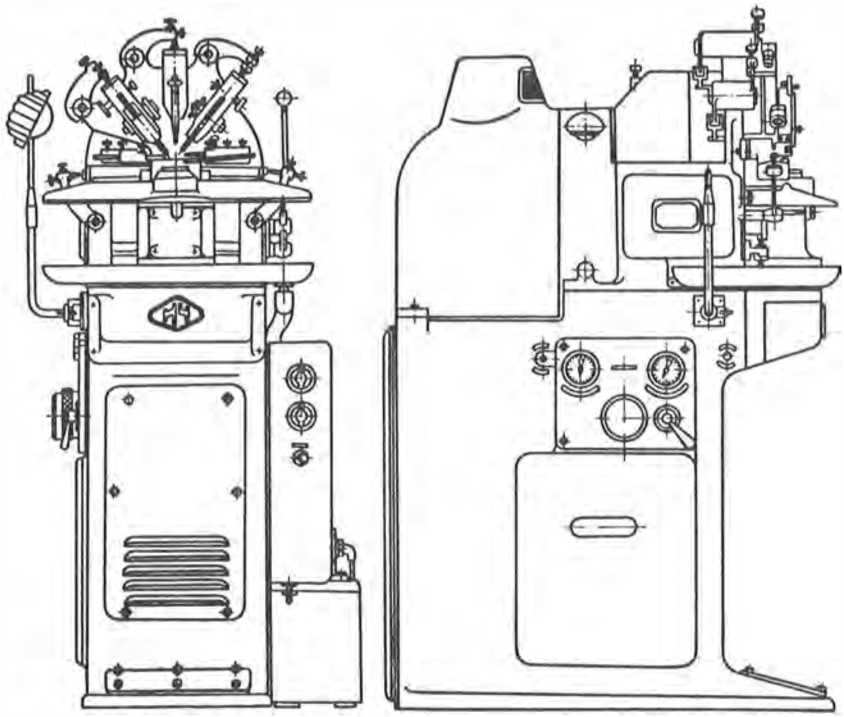
The blanked part is subjected to a preliminary forming of the rim, the hub, the central arm, and the windows are pierced (Figure 50, b). The operation is performed in a die on embossing presses or friction presses (or in crank presses if the above-mentioned types are not available). The formation of a hub of 0.4 mm height is an unavoidable result of the flow of material during forming. The preliminary forming is followed by the final forming of the rim and cold working of the central arm (Figure 50, c). The hole is shaved to its final dimension. A 0.15 mm local growth of the rim thickness occurs in the dotted zone and is removed in the following operation by grinding with an emery wheel.

The balance obtained by the swaging method is then shaved in a die on its outside and inside diameters and on the central arm contour (Figure 50, d), after which it is subjected to a stress-relieving operation.

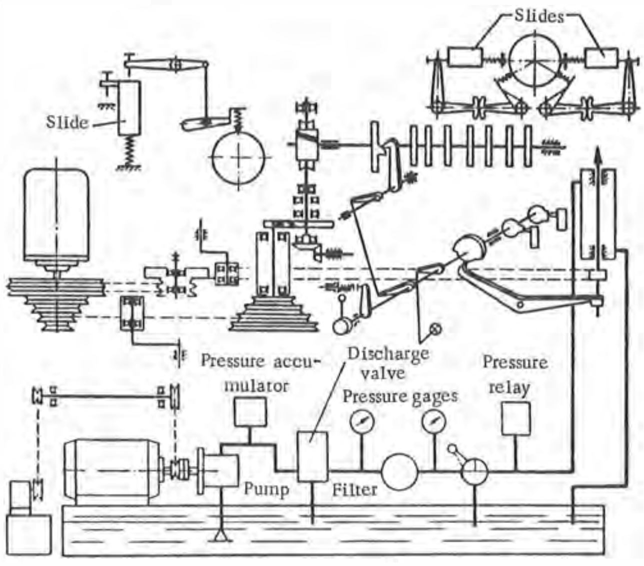
Drilling, countersinking, and thread tapping, are carried out in the same way as was described earlier.

The swaging method is more productive than the machining process: the number of operations is greatly reduced, and the time consumed is 1/3 to 1/4 of that required by machining.

Machining is followed by balance assembly: the screws are screwed into the rim, the staff is introduced into the hole, and the balance is compensated. Since the mechanical operations (the press operations excepted) are conducted on special [semiautomatic] machines, the cutting conditions and



a



b

FIGURE 49. T-229 semiautomatic finish-turning machine: a–general view; b–kinematic scheme.

the production rate for each operation are not calculated, but are established in accordance with the machine kinematics. Each operation is followed by either random or 100% inspection.

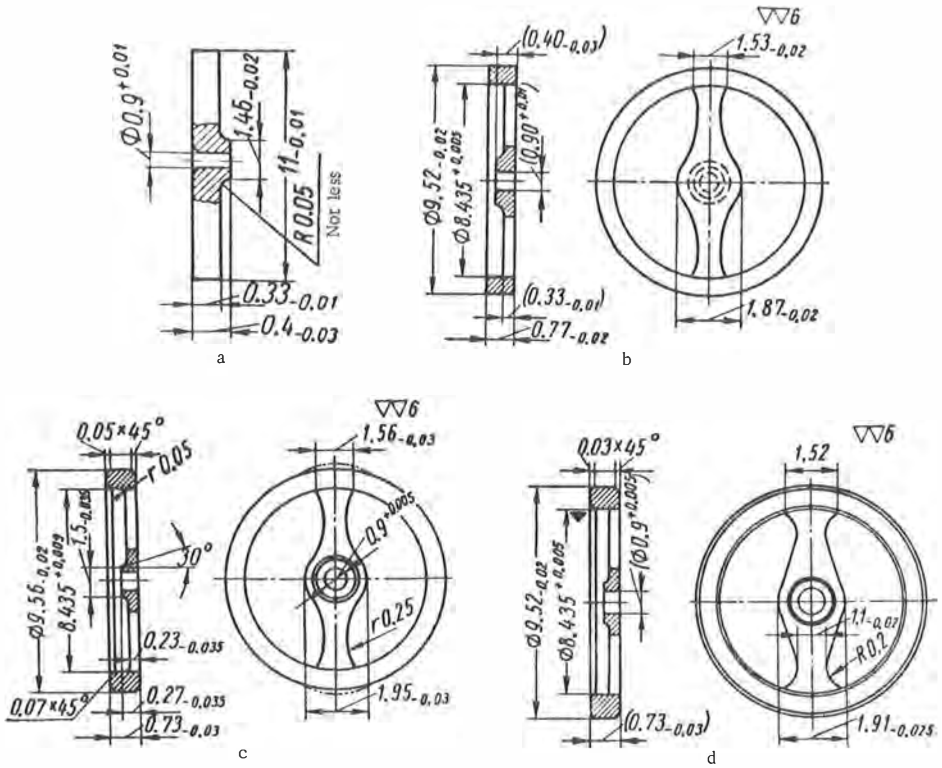


FIGURE 50. Operational sequence of the process of balance-rim manufacture by swaging

THE DOUBLE ROLLER

The double roller performs the following functions in the escapement. It transmits impulses from the pallet fork to the balance through the impulse pin (1), mounted in the upper roller (2) (Figure 51), and so maintains the balance oscillations. The lower roller (3), in its interaction with the guard pin, prevents the pallet from unlocking the escape wheel except when the impulse pin is in the pallet fork notch. The friction in the contact between the guard pin and the cylindrical surface of the roller must be a minimum. To that end, the surfaces of the lower roller are polished to a class 10 or 11 surface-finish quality. A hollow is milled in the lower roller to pass the guard-pin when the balance and the pallet fork are in contact. Double rollers are made of brass, beryllium bronze and steel. Brass rollers give satisfactory results, but the best results are obtained by hardened steel rollers with polished cylindrical surfaces.

The impulse pin works in impact, and, accordingly, it must be rigidly fastened to the upper roller. The hole for the impulse pin must be positioned symmetrically relative to the lower roller hollow and its center must be on the same radius with that of the center of the hollow.

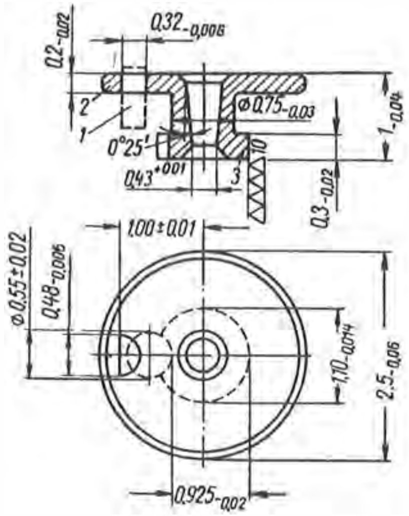


FIGURE 51. Double roller

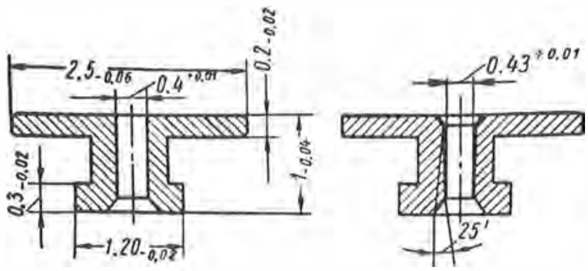
1–impulse pin; 2–upper (impulse) roller; 3–lower (safety) roller.

The brass double-roller blanks, which have a class 7 or 8 surface-finish quality, are turned on Swiss-type automatic screw machines (Figure 52, a) and the central hole is then countersunk from the upper roller side on the S-3M drilling machine.

The central hole is then shaved to a diameter of $0.43^{+0.01}$ (Figure 52, b) on the S-10 bench power press. This is followed by the piercing of the hole for the impulse pin in the upper roller, and the punching of the hollow for the guard pin in the lower roller. These operations are performed by a combination die in the S-10 press. The maximum allowable shift of the hollows relative to the axis of symmetry of the impulse pin is 0.015 mm.

The safety roller surface is then shaved to a ∇∇∇∇10 finish in a special die. The permissible run-out of the surface relative to the central hole is 0.01 mm. The roller to be shaved is placed on the bushing (6) (Figure 53) in the lower base (1) and positioned by the roller hole on guide pin (2). The upper die (3), with the bushing (4) fixed in it, shaves the surface. The knockout (5) removes the roller from the die after the bushing (4) has been withdrawn upward.

The designs of die (3) and bushing (4) are shown in Figure 53, b.



a b

FIGURE 52. Operation drawings for the double roller:

a–screw-machine blank; b–hole shaving.

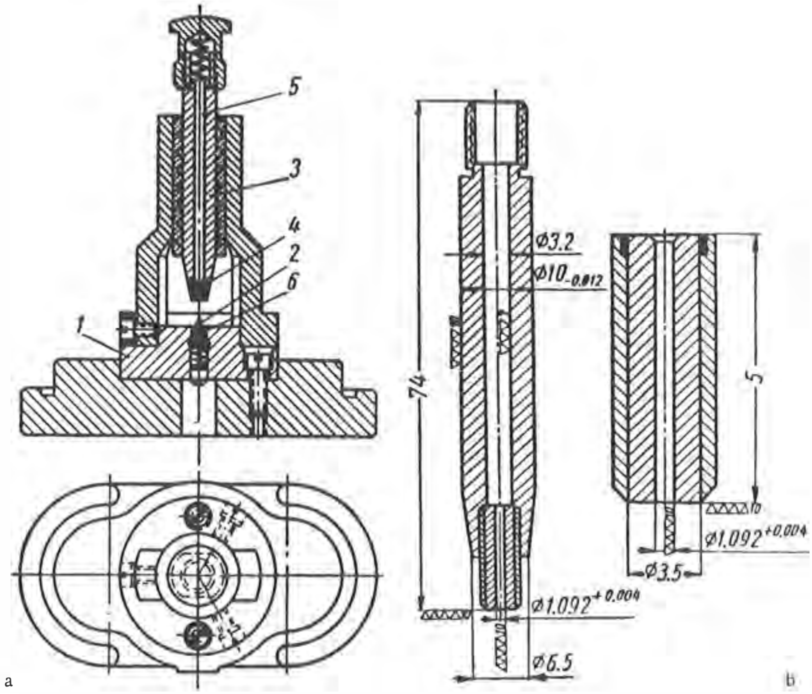


FIGURE 53. Shaving die for the cylindrical surface of the double roller

a–general view; b–die.

THE HAIRSPRING

The balance and hairspring are the most critical assemblies in the watch movement. The hairspring must pulsate (vibrate) uniformly in coiling and uncoiling, and therefore the spiral coils must not touch during their operation. The terminal curves must be so shaped that the center of gravity of the hairspring coincides with its geometrical center. The temperature coefficient of the material from which pocket- and wristwatch hairsprings are made must not exceed 0.5 sec/deg. cent. The surface-finish quality must be class 11 or 12.

The blank of the "Pobeda" wristwatch spring is shown in Figure 54. The spiral thickness is $h = 0.035^{\pm 0.001}$ mm. The reason for the narrow tolerance is that in the formula for the constant k of the hairspring moment $\left(k = \frac{Ebh^3}{12L}\right)$ h appears to the third power, so that small thickness deviations lead to a considerable variation in the hairspring moment. Hairsprings are manufactured by repeatedly drawing wire, flattening it, cutting it to blanks of the required length, coiling the blanks in a barrel (in groups of four) to give them the shape of an Archimedean spiral followed by heat treatment of the coiled springs in order to stablize their shape (form fixing), and lastly separation of the stabilized hairsprings.

The hairsprings are inspected for moment, surface quality and spiral shape.

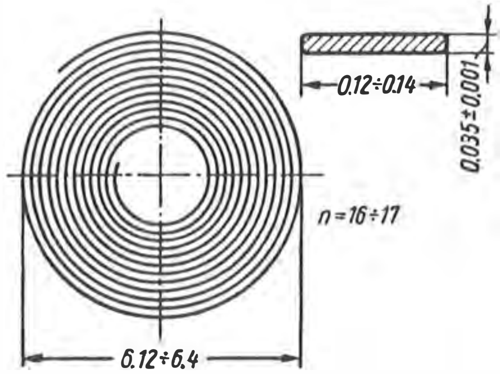


FIGURE 54. Blank of "Pobeda" watch hairsprings

Drawing. The wire used for hairsprings, of 0.26–0.30 mm diameter, is made from the N35KhMV alloy and has the following properties: bright surface, ultimate tensile strength σ_u = 78 to 88 kg/mm^2, elongation i = 17 to 20%, and modulus of elasticity E = 18,500 to 19,500 kg/mm^2.

The wire is drawn, in the watch plants, in several stages to the design diameter (D_n). The number of draws is determined from the difference between the wire diameters in the initial and final drawing stages, taking into account its mechanical properties.

A reduction coefficient h is calculated from the formula

$$h = \frac{F_{n-1} - F_n}{F_{n-1}} \cdot 100\%$$

or

$$h = \frac{D_{n-1}^2 - D_n^2}{D_{n-1}^2},$$

for each pass or group of passes,

where h = reduction coefficient in %,

F_{n-1} = cross-sectional area of the wire after the preceding pass, mm^2;

F_n = cross-sectional area of the wire after the given pass, mm^2;

D_{n-1} and D_n = corresponding wire diameters.

The reduction coefficient for the first drawing stage is 19 to 20% and for the final stage it is 10 to 12%. The reason for this is that the wire work-hardens with the drawing, and σ_u increases to 125 kg/mm^2. The speed of drawing is increased somewhat by reducing the reduction coefficient. The speed is 15 to 18 m/min at the beginning, and 22 to 26 m/min in the end.

The wire is drawn from 0.30 mm diameter to 0.20 mm diameter through carbide dies, and from 0.20 mm diameter to its final dimension of 0.075 to 0.08 mm (or 0.055 mm) through diamond dies.

Drawing dies are manufactured according to GOST 3919–47 and 6271–52. A carbide die of 8 mm outer diameter and 5 mm height is shown in Figure 55.

The die presents three sections: an exit hollow with a radius of curvature r = 1.5 and working cone with an angle of 40°, and a calibrating portion of a height of $\delta = 6d$.

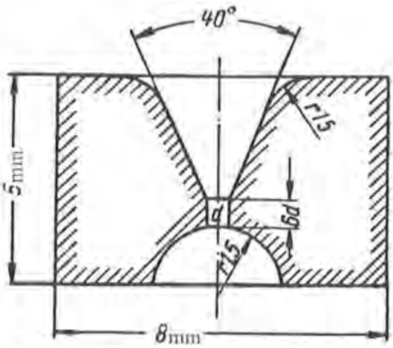


FIGURE 55. Carbide die

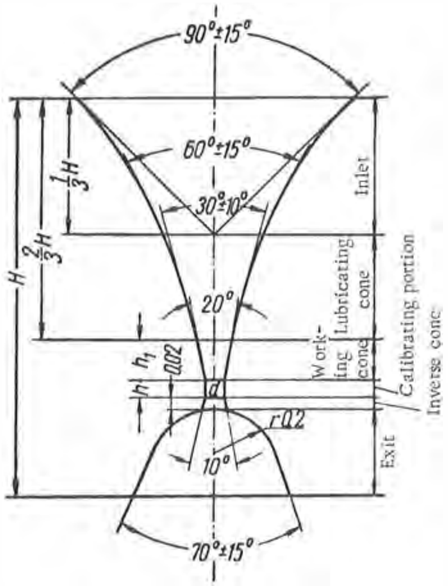


FIGURE 56. Diamong die

A diamond die is shown in Figure 56. It has four working zones and an exit cone. The entrance has cone angles of 90° and 60°. The lubricant cone has an angle of 30° and the working cone is 20°. The calibrating cylinder has a diameter equal to the diameter required for the hairspring.

Specific values of H, h, and h_1 (see Figure 56) corresponding to each draw are given in Table 1.

TABLE 1

Dimensions of diamond dies

Drawing diameter d, mm		H	h	h_1
nominal	tolerance			
0.003	+ 0.001	1	1d	2d
0.003 to 0.06	+ 0.0015	1.2		
0.06 to 0.10	+ 0.0025	1.4		
0.10 to 0.30	+ 0.005	1.6		

The wire is drawn on the S-64M machine. The lubricants used are vaseline oil or soap emulsion in the first passes, and aviation fuel in the last passes. The wire, during the drawing process, passes between felt pads which clean it.

The kinematics of the S-64M drawing machine are shown in Figure 57. The drawing speed is varied (between 15 and 26 m/min) by transferring the V-belt on the 4-step drive pulley.

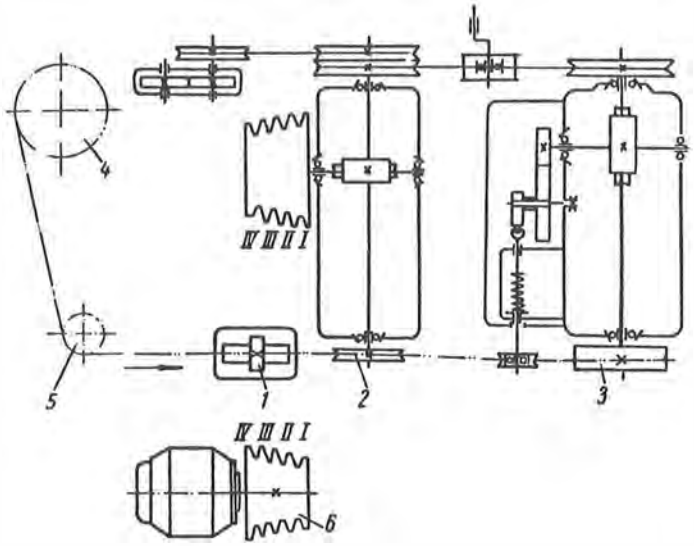


FIGURE 57. Kinematic scheme of the S-64M machine:

1–die; 2–drawing pulley; 3–winding reel; 4–stock reel; 5–guide idler.

Technical data, S-64M machine

Maximum drawing diameter, mm	0.5
Drawing-pulley speeds, rpm	80, 96, 115, 137
Drawing speed, m/min	15–26
Electric motor	0.6 kw, 1400 rpm

TABLE 2

Drawing sequence			Drawing speed*, m/min	Drawing sequence			Drawing speed m/min
draw, mm	die-plate diameter, mm	coefficient of draft, %		draw, mm	die-plate diameter, mm	coefficient of draft, %	
0.30–0.27	0.270	19	15–18	0.140–0.130	0.130	13.5	15–18
0.27–0.240	0.240	21	15–18	0.130–0.120	0.120	14.5	15–18
0.240–0.220	0.220	16	15–18	0.120–0.110	0.110	16	15–18
0.220–0.200	0.200	17	15–18	0.110–0.100	0.100	17	15–18
0.200–0.180	0.180	19	15–18	0.100–0.095	0.095	10	22–26
0.180–0.170	0.170	11	15–18	0.095–0.090	0.090	10	22–26
0.170–0.160	0.160	11.5	15–18	0.090–0.085	0.085	11	22–26
0.160–0.150	0.150	12	15–18	0.085–0.080	0.080	11	22–26
0.150–0.140	0.140	13	15–18	0.080–0.075	0.075	12	22–26

The tolerance on dimensions > 0.200 mm = ± 0.002. The tolerance on dimensions < 0.200 mm = ± 0.001 mm.

* The drawing speed has been increased 4 to 5 times in latest drawing machines.

Table 2 gives the drawing sequence for the "Pobeda" watch hairsprings made of N35KhMV alloy.

Flattening of the wire is performed in the special D-63 two-high rolling mill (Figure 58). The design diameter D_n is determined using the empirical formula

$$D_n = \frac{h+b}{2},$$

where h = the hairspring thickness;

b = the hairspring width.

For the "Pobeda" watch hairspring this formula gives

$$D_n = \frac{0.035+0.12}{2} = 0.0775 \text{ mm}.$$

For high values of σ_u the value D_n = 0.075 mm is used.

Flattening is possible if $\frac{b}{h} \leqslant 10$. If $\frac{b}{h}$ is more than 10, rolling will not produce the required width but will increase the length instead.

The $\frac{b}{h}$ ratio for the hairspring being discussed here (h = 0.035 mm, b = = 0.12 mm) is $\frac{0.12}{0.035}$ = 3.4, which is well below the upper limit. The quality of the strip surface is a function of the state of the roller surfaces only.

The surface quality of the strip must be class 11 or 12 in order to protect the hairspring from corrosion. The lateral edges of the strip inevitably have microfractures resulting from the flattening, and their surface quality is class 8 or 9.

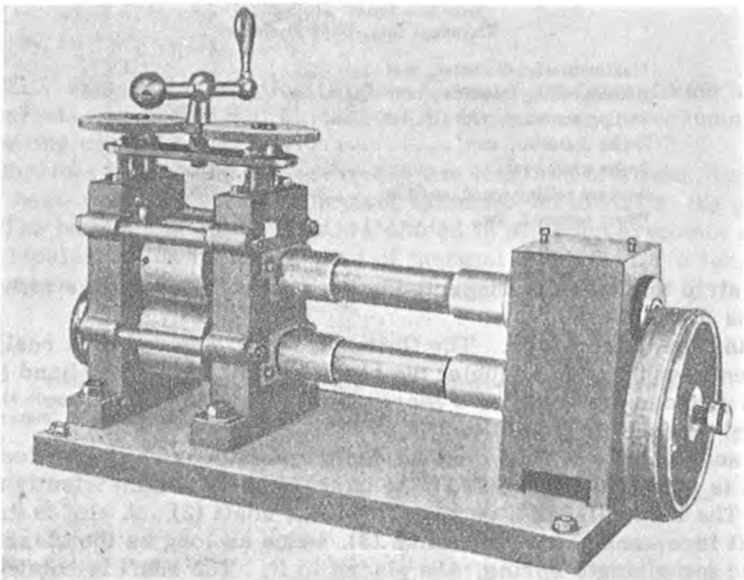


FIGURE 58. D-63 two-high rolling mill

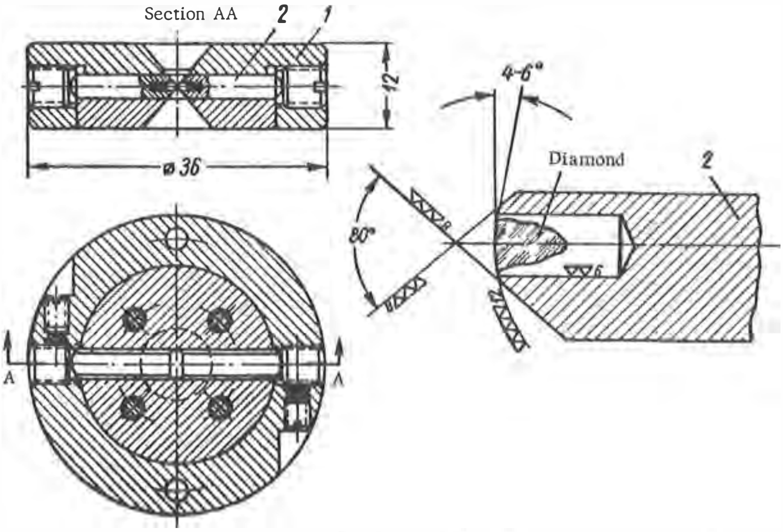


FIGURE 59. Diamond die

A certain waviness is imparted to the strip surface by the unavoidable roller run-out. The wave length is equal to the roller circumference. A run-out tolerance of 0.002 mm is established for the rollers in order to minimize these fluctuations and, in addition, the strip is subsequently drawn through a diamond die (Figure 59). Ring (1) holds the two adjustable mandrels (2), with diamond grains cemented in them.

Technical data, D-63 machine

Maximum wire diameter, mm	1
Normal rolling thickness, mm	0.03—0.05
Rolling accuracy, mm	0.001
Roller diameter, mm	84
Roller width, mm	60
Average rolling speed, m/min	15
Power required, kw	0.5

The strip thickness is inspected using a lever micrometer with scale divisions of 0.001 mm.

Coiling the hairsprings. The flattened strip is wound on a reel of circumference equal to (or double) the blank length, and cut by hand scissors; for this purpose the reel has a longitudinal slit. The blanks are then coiled in barrel devices in groups of 3, 4 or 5.

The scheme of a device used for the simultaneous coiling of four hairsprings is shown in Figure 60. The barrel has two diametrically opposite slots. The barrel (1) is a running fit on the shaft (2). A slot is milled in the shaft face, and two strip blanks (3), twice as long as the blank length required for a single spring, are placed in it. The shaft is rotated by the drive, and the hairsprings coil up. Two cutouts on the external shoulder of the barrel which engage two pins and thus position the barrel in the device prevents its rotation. The coiling continues till the whole internal

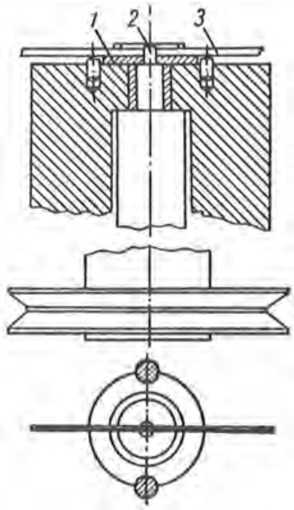


FIGURE 60. Hairspring-coiling device

area of the barrel is filled by the blanks. The strip ends which protrude are then cut off. The barrel is easily removed from the shaft and covered with a lid. The barrels are then placed in a container (Figure 61) and loaded in a furnace for form-fixing (stabilizing) treatment.

The form-fixing heat treatment of the hairspring, at a specified temperature and for a specified duration, is performed for the purpose of causing the spring to maintain the spiral form imparted to it by the coiling process.

Form fixing is a critical operation. Very small fluctuations in the process conditions lead to sharp variations in the hairspring form. The dependence of the hairspring form on the heat-treatment conditions is illustrated in Table 3 by the example of the "Molniya" pocket-watch hairspring (according to laboratory experiments).

The best results were obtained in the first and fourth cases. No darkening of the polished hairspring surface during heating and cooling is permitted. Accordingly, hairsprings are now form-fixed in vacuum installations at a pressure of 1.2×10^{-4} mm mercury.

FIGURE 61. Barrel container

The UFV vacuum installation (Figure 62) used for form-fixing heat treatment consists of two thermal blocks, an electric heater, a vacuum system, and a heating control panel.

The thermal blocks are cylinders 800 mm long and of 80 mm diameter, made of heat-resisting steel. They are fastened vertically to the panel front. The hairspring containers are placed in six compartments symmetrically located inside the lower part of thermal block (1) for a length of about 400 mm from the end.

TABLE 3

Hairspring properties and form fixing as a function of the process conditions

Temperature, °C	Holding time, min	σ_u kg/mm^2	i,%	Results
700	21	103	5.6	Form normally fixed
680	19	103	5.6	Form not fixed
680	30	111	3.2	Form not fixed
680	45	99	5.3	Form normally fixed

Vacuum chambers (2), connected by a vacuum duct with the vacuum system located inside the cabinet, are mounted in the upper part of the thermal block. The thermal blocks are covered from above by a lid with a rubber seal which prevents air inflow during operation. A valve is mounted in the lid, and argon is introduced into the thermal block (from a cylinder).

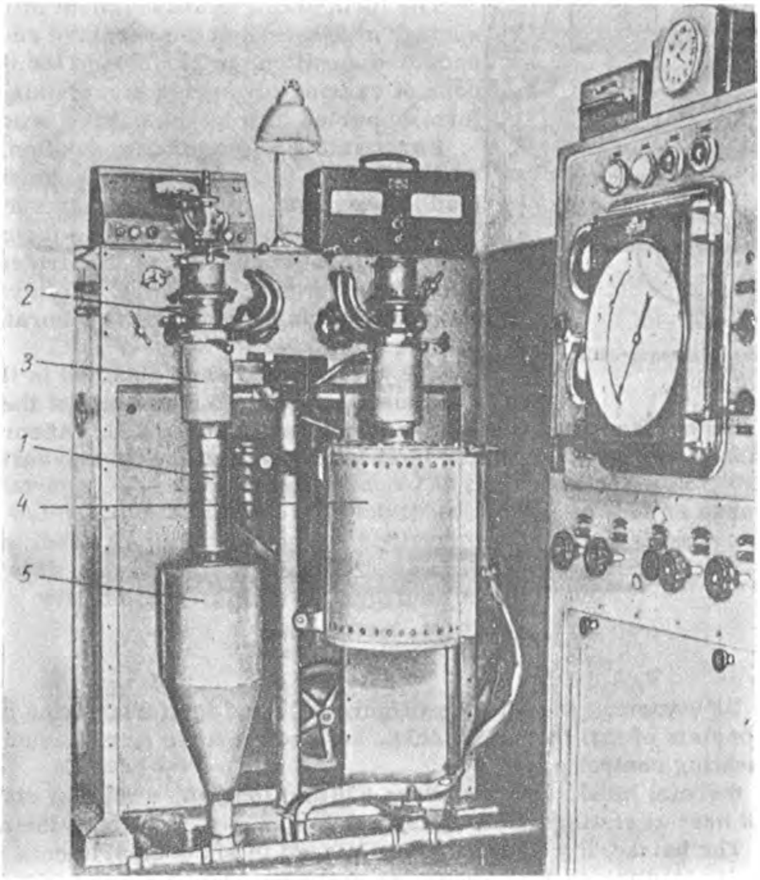


FIGURE 62. UFV vacuum installation for hairspring form-fixing

The coolers (3) are mounted on the outside of the thermal blocks and provide an intensive water spray after the fixing process has been terminated.

The inert gas argon and the cool water quicken the process of cooling the thermal block. The conical tank (5) collects the water from the thermal block and returns it to the system.

The thermal blocks are heated by the electric heater (4), which is held on a bracket and can move vertically or sideways, and rotate ±90°, and so heat the two thermal blocks in turn.

The vacuum system is mounted behind the panel and includes: the VN-461 backing pump (Figure 63), and the TsVL-100 diffusion pump with a drip pan, a vacuum duct, the cocks (1–7), the electric motor, and the cooling system.

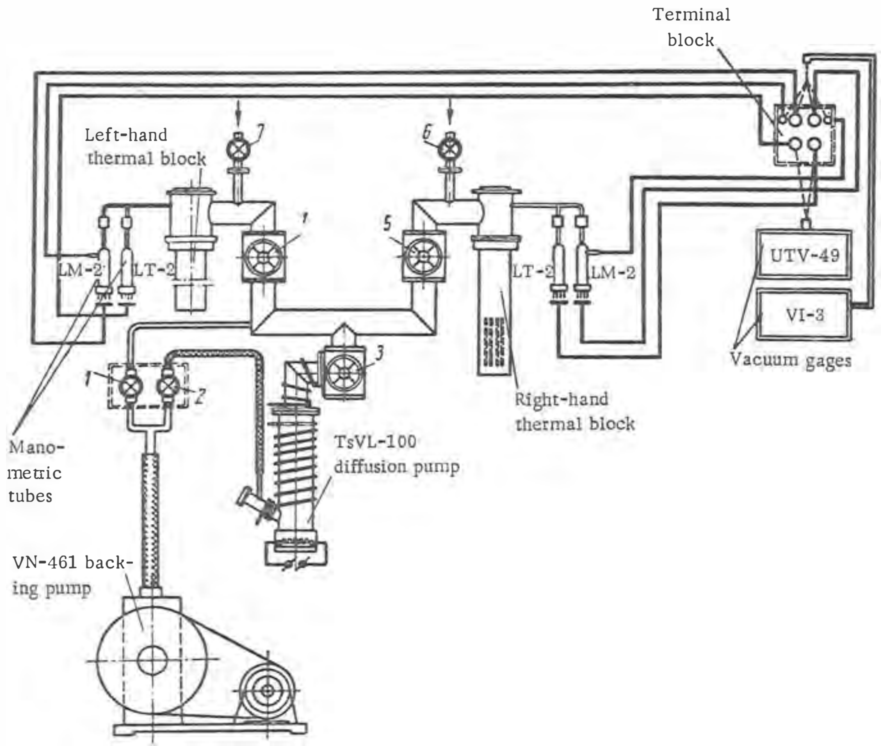


FIGURE 63. Basic scheme of the vacuum installation

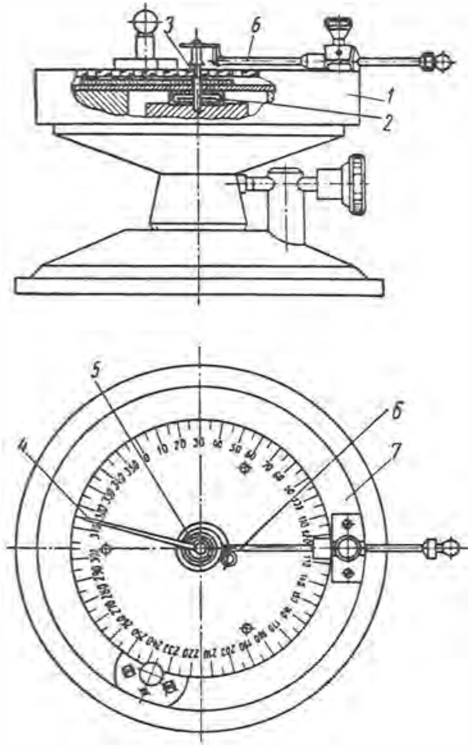


FIGURE 64. Instrument for the determination of hairspring torque

The vacuum-system instrumentation is placed on the side and upper parts of the cabinet.

The control panel provides for the automatic and manual adjustment of the temperature in the working space of the heater. The EPD-17 electronic potentiometer, signal lamps and other additional instruments are mounted in its upper part.

The electronic potentiometer indicates, records, and adjusts the temperature in the working zone of the heater.

The container with the hairsprings to be form-fixed (800–1000 pieces) is loaded in one of the thermal blocks, and the chamber is then closed by gasketed lids. The backing pump is switched on and the pressure reduced to 5×10^{-3} mm mercury. The diffusion pump is then switched on and the pressure reduced to 1×10^{-4} mm, at which the surface of the heated hairsprings does not acquire oxide or dark tints (the surface darkens at a pressure as low as 5×10^{-4} mm mercury).

Down to 5×10^{-3} mm the pressure is measured by the UTV-49 vacuum meter together with the LM-2 pressure gage. The VI-3 ionization vacuum meter in conjunction with the LT-2 tube is used for vacuums down to 1×10^{-4} mm.

The next stage consists in positioning the electric heater under the thermal block and lifting it until the whole lower working part of the thermal block is within the heater. The cooler is transferred to its upper position. The time relay controlling the holding time at the specified temperature is switched on when this temperature is reached. A signal at the end of the period causes the electric heater to be drawn away from the thermal block. The cooler is lowered to the heated part of the thermal block and filled with water, after which it directs a strong jet against the thermal block. Argon is fed into the chamber from the cylinder. The containers are unloaded after the thermal block has been cooled, and a new batch is charged into the block. The second thermal block is heated while the first is being cooled, unloaded and loaded. A considerable period of time (up to an hour and a half) is required to produce the necessary vacuum.

The holding time at 700°C for hairspring form-fixing is 21 to 23 min. The cooling time is 50 min.

Technical data for the vacuum form-fixing installation

Power consumed, kw	4.5
Supply voltage, v	220
Maximum heater power, kw	3.5
Maximum heating temperature, °C	950
Dimensions of the working volume of the heater, mm:	
diameter	90
length	500
Length of the uniformly heated zone, mm	200
Allowable temperature gradient in the uniformly heated zone, °C	Not more than 10
Working-section heating temperature, °C	600–700
Warming-up time for the parts (or the thermal block), min	Up to 75
Temperature adjustment	Automatic
Residual pressure in the thermal block, mm mercury	1×10^{-4}
Pumping-out time, hours	Up to 1.5
Number of hairsprings which can be processed per installation in 8 hours under steady conditions	10,000
Coolant	Water

Hairspring inspection. The form-fixed hairsprings are taken out of the barrels with pincers and separated by shaking. A random inspection is then carried out of their geometrical form (using a profile projector) and of their torque (using the instrument shown in Figure 64).

A master hairspring (2) is placed inside the cast-iron body (1) of this instrument. The outer end of the hairspring is rigidly fastened to the body, while its inner end is fastened to the vertical shaft (3). The same shaft carries the pointer (4).

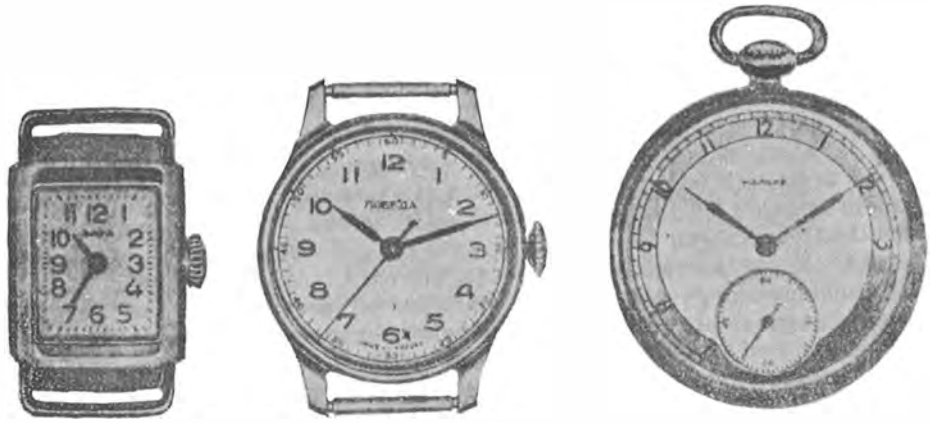
The inner end of the hairspring to be tested (5) is fastened in the shaft chuck, and the outer end is fastened in the holder (6). The holder is rotated 360° together with the revolving rim (7), and so loads the hairspring being tested. The hairspring in turn loads the master hairspring through the shaft (3) and the angle through which the shaft is rotated is proportional to the torque of the hairspring being tested. The value of the angle of rotation of the shaft is indicated by the pointer (4) on the instrument scale. The relationship of the angle of rotation and the torque of the hairspring being tested is given in a special table.

The same process of drawing and flattening is also used for bronze alarm-clock hairsprings. The heat treatment of these springs is performed in laboratory muffle furnaces.

Chapter VIII

THE MANUFACTURE OF CASES, DIALS AND HANDS

The case, dial and hands are the parts which determine the external appearance of a watch (Figure 1). Watches having the same movement can vary in external appearance and the greater the diversity in models, the more will popular demand be satisfied.



a b c

FIGURE 1. External appearance of wrist- and pocket-watches:
a—"Zarya" watch; b—"Pobeda" watch; c—"Molniya" watch.

The external parts must satisfy the basic requirement that their surface finish be preserved for many years. Accordingly, their protective coatings must be able to resist not only mechanical influences (the case coating), but also the influence of light (the dial coating). Specific manufacturing methods have been evolved for each part in order to satisfy these requirements.

CASES

Not only must watch cases preserve their external finish, they must also be hermetically sealed, so as to protect the watch movement against dust, and in some cases (on special order), against humidity as well. Case shapes and manufacturing methods are very varied but it seems sufficient to examine the manufacturing methods used in making the "Pobeda" wristwatch case and the "Molniya" pocket-watch case, which are typical to a certain extent.

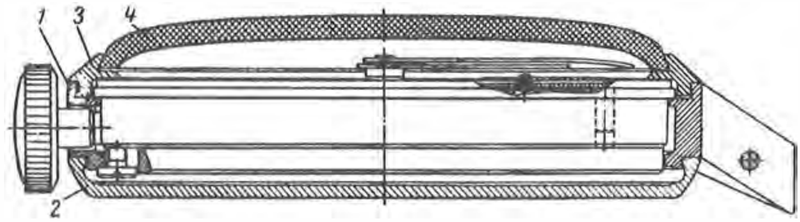


FIGURE 2. "Pobeda" wristwatch case

The wristwatch case is assembled from the middle (1), the back (2), the bezel (3) and the crystal (4) (Figure 2). The middle and bezel are made of MNTsS 63-17-18-2 lead nickel-silver and the back is made of 1Kh18N9 stainless steel while the crystal is plexiglass. The middle and the bezel are chromium-plated, while the back is not coated. This combination of materials and coatings protects the case against corrosion and rubbing.

The pocket-watch case is assembled from the case middle (1), the pendant (2), the bow (3), the back (4), the bezel (5) and the crystal (6) (Figure 3).

The middle, the pendant, the bow, the bezel and the back are made of MNTsS 63-17-18-2 lead nickel-silver and chrome-plated. The crystal is made of silicate glass.

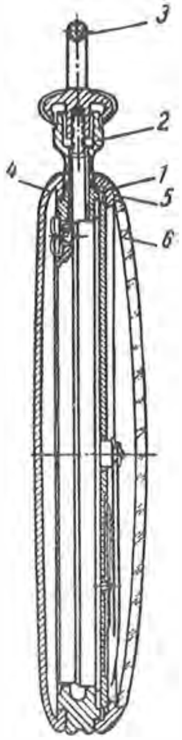


FIGURE 3. "Molniya" pocket-watch case

WRISTWATCH CASE MIDDLES

The middle is of complex configuration. Lugs for the strap bars are an integral part of the middle and there are several strictly concentric projections and recesses to take the watch movement, the bezel and the back (Figure 4).

The middle is blanked from strip material by a combination die (Sh-04) on a 35-ton crank press (first operation). The contoured punch face simultaneously bends the lugs to a 13.8 mm radius (Figure 5). The blank is then artificially aged (second operation) for two hours in the PN-316 electric shaft furnace at 340–360°. It is then twice countour-shaved (Figure 6) by the Sh-03 shaving die on a 35-ton crank press (third operation).

The lower shoe (1) of the shaving die carries the nest (5) (Figure 7), the props (11) and (13), the first-shaving and second-shaving dies (12) and (15), the back-up rings (19) and (6), the cushion (20), the pins (14), (17), and (18), and the screws (10) and (16).

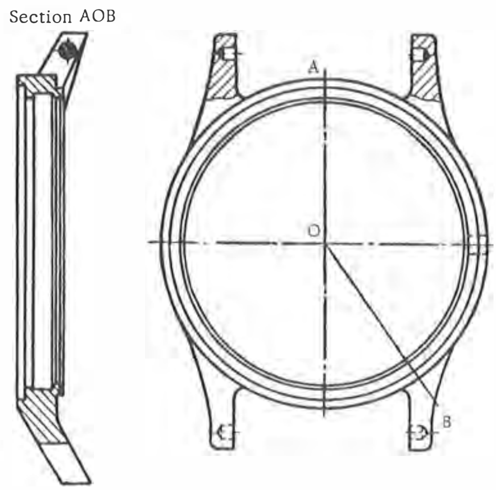


FIGURE 4. "Pobeda" watch-case middle

The upper shoe (2) carries the contour punch (8), the guide pin (4), the pins (7), and the screws (3), and (9).

The blank to be shaved is inserted into nest (5) which positions it by its contour relative to the contour of die (12). When the upper shoe (2) is lowered, the conical part of the guide pin (4) penetrates the blank hole and positions it definitely relative to the punch contour (and therefore relative to the die contour as well), ensuring a uniform thickness of the middle walls. The dies are made up of four sections each and are held together by back-up rings; this arrangement facilitates accurate grinding of the lug profile.

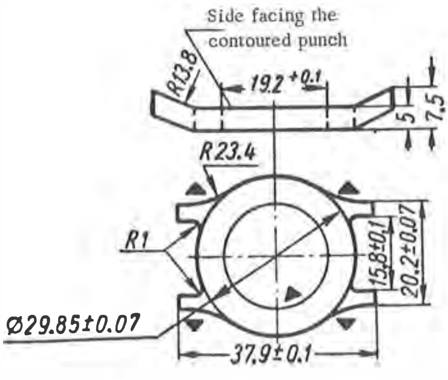


FIGURE 5. Blank of case middle

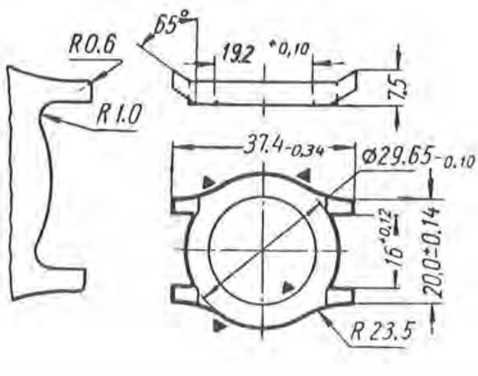


FIGURE 6. Shaved middle blank

The shaved blank is then faced on a special semiautomatic lathe, and the hole is bored (Figure 8) (fourth operation). The faces serve as reference surfaces for the subsequent machining. The blank to be faced and bored is clamped in a collet chuck (Figure 9), consisting of the collet (1), the body (2), the plate (3) held by the screw (4) against the post (5), the mount (6), and the contour plate (7).

The inside face of the blank is pressed against the chuck mount (6) and the lugs are gripped by the contour plate (7) when the collet (1) is withdrawn to the left and compressed. The contour plate is made up of four separate parts fastened to the collet face. The part is ejected from the chuck when the collet opens.

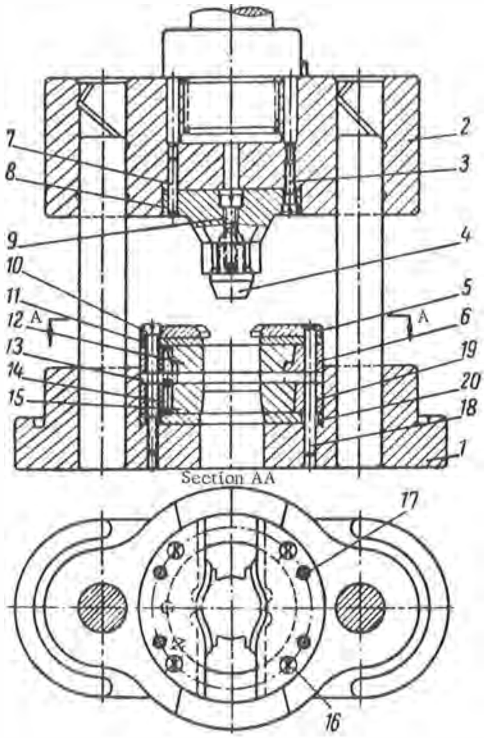


FIGURE 7. Shaving die

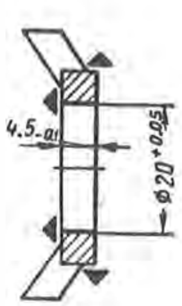


FIGURE 8. Boring and facing the middle

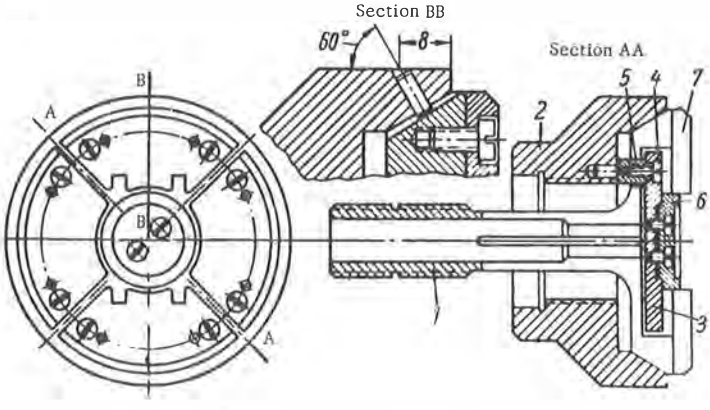


FIGURE 9. Chuck for gripping the middle during boring

The fifth operation consists in facing and boring a 26.5 mm diameter recess (Figure 10) on the S-175 semiautomatic machine (Figure 11a).

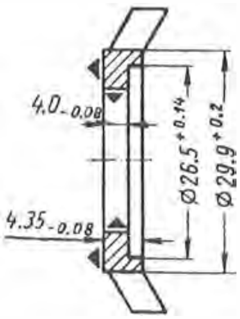


FIGURE 10. Boring the case middle recess

The blank is gripped in a special collet chuck. The S-175 machine was specially designed for turning case middles, bezels and backs and for threading these parts in the case of hermetically sealed cases. The entire profile of one side of the part, threads included, can be machined in one chucking. The machine is driven by an electric motor (Figure 11b). The V-60 variable-speed drive allows stepless control of the main-driveshaft (I) speed between 120 and 2250 rpm.

The speed of rotation can be varied by the handle (1) while the machine spindle (2) is revolving. It is possible for the electric motor to drive the main driveshaft directly, without the variable-speed drive.

The main driveshaft drives the pulley on spindle (2), which revolves at speeds between 175 and 3100 rpm, and also drives the feed driveshaft II through the countershaft III and an eight-step pulley. The feed driveshaft drives the camshaft IV through a worm and wheel. The keyed sleeve (10) can transmit power to the feed shaft II either from a four-step pulley or from the machine spindle through three spiral gears, the latter transmission being used for threading.

The threading transmission is engaged by the handle (3). The following cams are located on camshaft IV: the slide transverse-feed cam (4), the slide cross-feed cam (5), the cam (6) of the transverse and cross-feed stops, and the threading cam (7). The worm wheel carries the stop (9), which switches off (stops) the machine after one machining cycle, that is, after one camshaft revolution. The pedal (11) opens the collet.

Technical data, S-175 machine

Maximum diameter of the part machined, mm ...	55
Maximum machining length, mm	25
Maximum thread pitch, mm	0.7
Spindle speed using the stepless variable-speed drive, rpm	150 to 3150
Number of camshaft speeds	16
Electric motor	1 kw, 1425 rpm

Several models of this machine, differing in their chucking fixtures, are produced and the machine can also operate with a magazine feed. The S-175 machine is equipped with a collet chuck (Figure 12), assembled from the collet body (1), the barrel (2), the collet expander (3), the collar (4), the washer (5), the spring (6), and the driver pin (7). The blank hole is positioned on the protruding cylindrical shoulder of the collet body (1) (3.5 – 3.8 mm depth). The face of the barrel (2) serves as a holding surface. The expander (3) opens the collet which grips the blank on its inner diameter. At the end of the operation the pedal is pressed, the expander is pushed to the right, the collet contracts and releases the blank. The collar (4) is moved to the right by the spring (6) and knocks the blank off the shoulder.

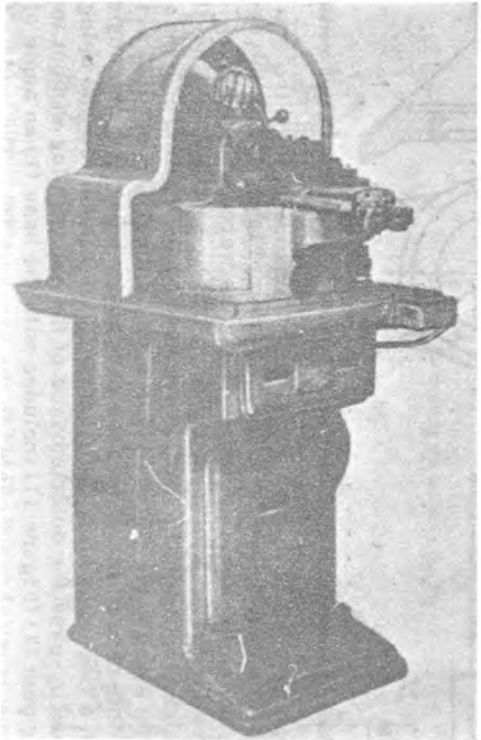


FIGURE 11 a. S-175 semiautomatic machine

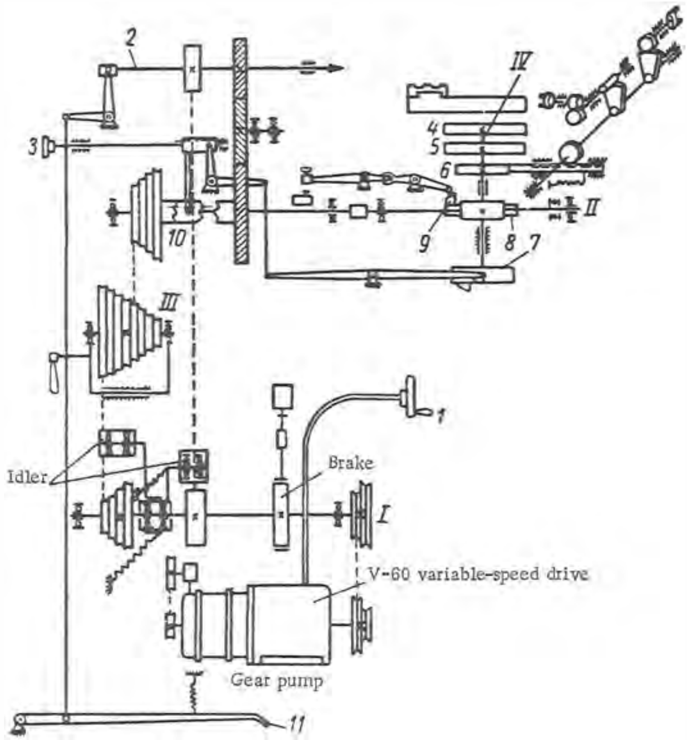


FIGURE 11 b. Kinematic scheme of the S-175 semiautomatic machine

The boring of the 26.5 mm diameter recess is followed by the boring of the bezel recess and facing (Figure 13). Thus, the sixth operation, is performed on the S-175 machine. The surfaces machined on the fourth and the fifth operation serve as holding and locating surfaces. The dimensional tolerances for this operation are narrower than those for the preceding operations.

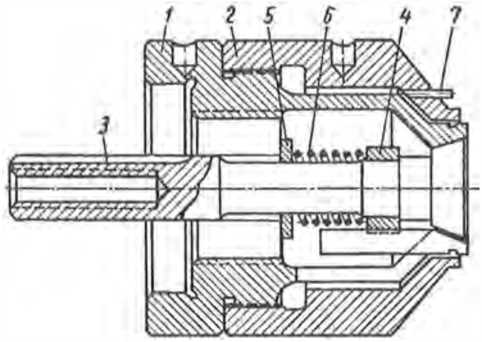


FIGURE 12. Expanding chuck for machining the middle

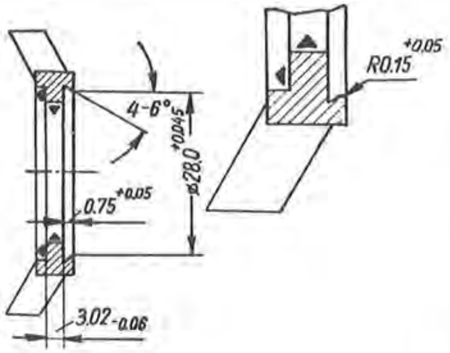


FIGURE 13. Boring the bezel recess (sixth operation)

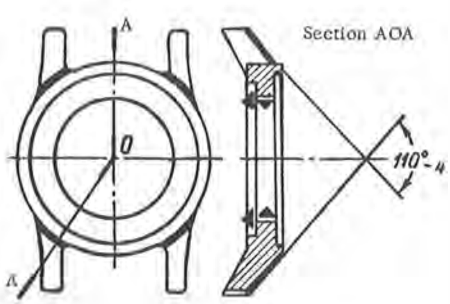


FIGURE 14. Lug turning (seventh operation)

The lugs are then turned (seventh operation, Figure 14) on the special S-1a lathe, using the same holding surfaces as were used above. Next, the shoulder for the back is turned (Figure 15) by a contour tool on the S-1a machine (eighth operation). This is followed by the drilling of four blind holes for the strap bars (Figure 16) in a jig on the S-106 vertical drilling machine (ninth operation). The axes of opposite holes make an angle of 8°–10° with a line connecting their centers, the reason for this being that the drill must by-pass the outer surface of the opposite lug without touching it. The jig post (2) (Figure 17) includes with the base (1) an angle of 80-82°. The drill bushings (5) are mounted in the brackets (4). The middle (3) is placed on the mount (6) and pressed by the pressure plate (8), hinged to the bracket (7).

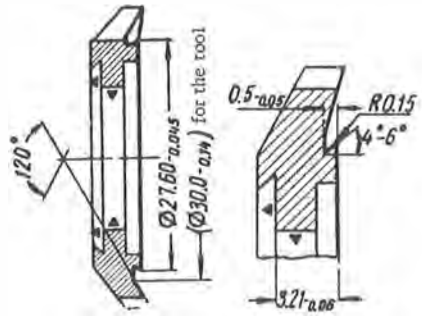


FIGURE 15. Turning the back shoulder (eighth operation)

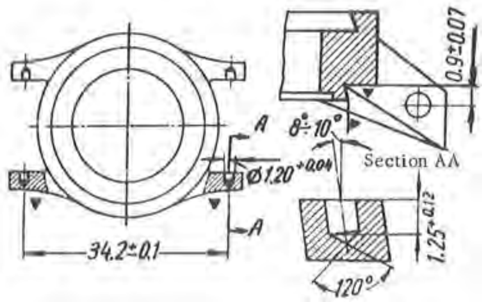


FIGURE 16. Drilling holes for the strap bar (ninth operation)

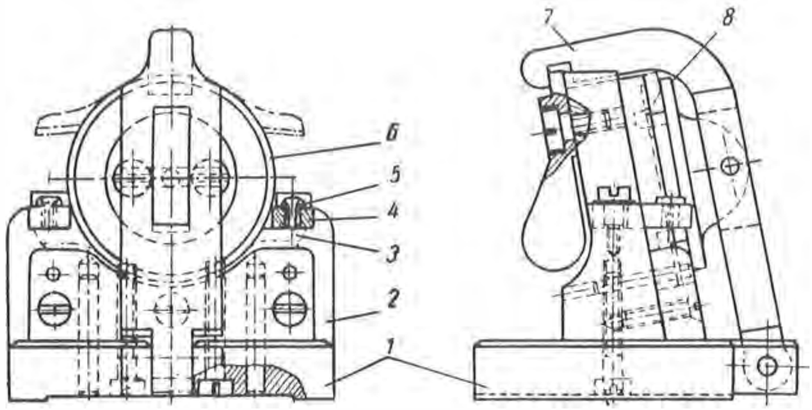


FIGURE 17. Jig for drilling the holes in the lug

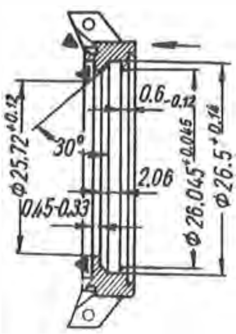


FIGURE 18. Boring the movement recess (tenth operation)

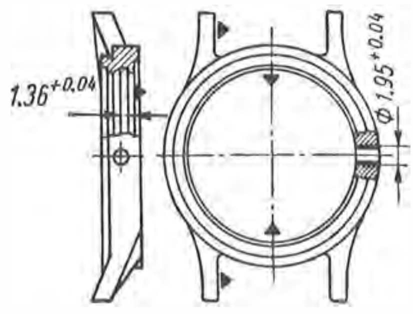


FIGURE 19. Drilling the winding-stem hole (eleventh operation)

The tenth operation consists in turning the recess for the moment (Figure 18). A form tool and either the S-175 or the S-81A machine are used for this operation. The drilling of the winding-stem hole (Figure 19) by a special horizontal semiautomatic drilling machine follows (eleventh operation). The case middle is finally polished (twelfth operation) and buffed in a longitudinal direction, and then plated (thirteenth operation).

Cutting conditions. The cutting conditions for facing and boring are established as a function of the machining diameter, the depth of cut, the surface-finish quality required, and the tool material.

The maximum machining diameter is introduced into the formula for calculation of the cutting speed. Taking this diameter to be d = 30 mm on the average, and taking n = 3150 rpm in the S-175 machine, we obtain

$$v_{max} = \frac{3{,}14 \cdot 30 \cdot 3150}{1000} \approx 300 \text{ m/min.}$$

The feed rate is established as a function of the surface-finish quality required and the radius of curvature of the tool cutting point. In the majority of cases the surface is machined to a class 6 or 7 finish (see Table 1).

The turning (basic) time T_t is determined using the formula

$$T_t = \frac{l + l_1 + l_2}{n \cdot s},$$

where l = turning length, mm;
l_1 = tool approach, mm;
l_2 = tool overtravel, mm;
s = feed, mm/rev;
n = rpm.

When working with semiautomatic machines, the machine cycle time is obtained by adding the idle cycle time $T_{i.c.}$, to the furning time T_t . The idle cycle time $T_{i.c.}$ is

$$T_{i.c.} = T_o \cdot \frac{n_{i.c.}}{360° - n_{i.c.}},$$

where $n_{i.c.}$ = the number of idle movement cam degrees, obtained either from the technical data of the machine or from the setup chart.

The piece time is the sum $T_t + T_{i.c.} + T_{aux}$; T_{aux} is calculated from the tables of standards.

The parts are subjected to a random inspection, using both universal and specialized instruments, after each operation. Comparators, indicators, calipers, and micrometers are examples of universal instruments, while plug gages and templates are examples of specialized instruments.

The above-described machining process has the shortcoming that the coefficient of metal use in the strip layout is only 33%. Simultaneous blanking of middle and bezel* was proposed and tested at the Watch Plant No. 2 in Moscow (Figure 20).

The method of simultaneous blanking increases the coefficient of metal use to 70%, because of the additional blank and because the values of the bridge a_1 between blanks and the strip-edge brige a_2 in the strip layout is reduced as compared with those given in Figure 11, Chapter III.

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* This method was proposed by M. I. Petetskii, M. A. Nesterov, and A. V. Gorskii.

TABLE 1

Feed rates for machining NMTsS 63-17-18-2 nickel silver as a function of the cutting speed and the surface-finish quality required (abridged form):

v, m/min	Radius of tool point, mm	R9 and R18 tools			VK6 and VK8 tools		
		Surface-finish-quality class					
		▽▽ 6	▽▽▽ 7	▽▽▽ 8	▽▽ 6	▽▽▽ 7	▽▽▽ 8
		Feed rates, s_0, mm/rev					
Longitudinal turning							
30–70	0	0.018	0.013	0.009	0.020	0.015	0.01
	0.3	0.019	0.014	0.010	0.021	0.016	0.011
	0.5	0.020	0.015	0.011	0.023	0.018	0.013
	0.8	0.022	0.017	0.013	0.025	0.020	0.015
Above 70	0	0.019	0.014	0.010	0.022	0.017	0.012
	0.3	0.020	0.015	0.011	0.023	0.018	0.013
	0.5	0.022	0.017	0.012	0.025	0.020	0.015
	0.8	0.024	0.019	0.014	0.027	0.022	0.017
Facing							
30–70	0	0.016	0.012	0.007	0.017	0.013	0.008
	0.3	0.017	0.013	0.008	0.018	0.014	0.009
	0.5	0.018	0.014	0.010	0.019	0.018	0.012
	0.8	0.019	0.015	0.011	0.021	0.016	0.012
Above 70	0	0.016	0.012	0.008	0.018	0.013	0.009
	0.3	0.017	0.013	0.009	0.019	0.014	0.010
	0.5	0.018	0.014	0.011	0.021	0.016	0.012
	0.8	0.019	0.015	0.012	0.023	0.018	0.014
Boring							
30–70	0	0.010	0.007	0.005	0.012	0.009	0.006
	0.3	0.011	0.008	0.006	0.013	0.010	0.008
	0.5	0.013	0.010	0.008	0.015	0.012	0.010
	0.8	0.015	0.012	0.010	0.017	0.015	0.012
Above 70	0	0.011	0.008	0.006	0.013	0.010	0.007
	0.3	0.012	0.009	0.007	0.014	0.012	0.009
	0.5	0.014	0.012	0.010	0.016	0.014	0.011
	0.8	0.017	0.014	0.012	0.019	0.017	0.014

Punch (1) and die (4) (Figure 21), in the proposed die set, pierce the central hole. Punch (2) and dies (3) and (4) blank the case middle. Punch (2) and die (4) blank the bezel which is then pressed back into the middle blank by the knockouts (5) and (6). Scrap results from the hole-piercing and in addition there is the between-lugs scrap and the scrap a_1 and a_2.

The middle blank is subjected to two expanding operations in the diametral direction in a die with a tapered punch.

The expanding is followed by lug-bending, after which the case-middle blank is identical in shape and dimensions with the blank obtained in the process described above.

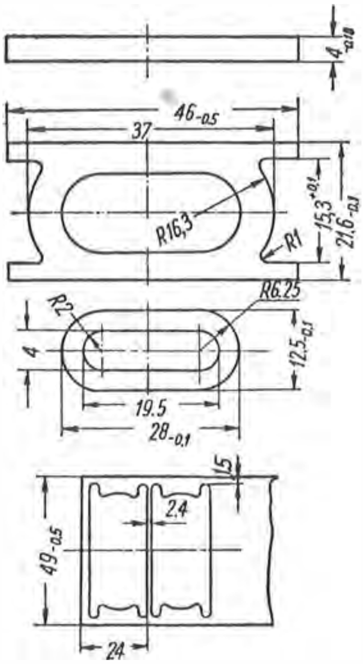

FIGURE 20. Shape of middle and bezel

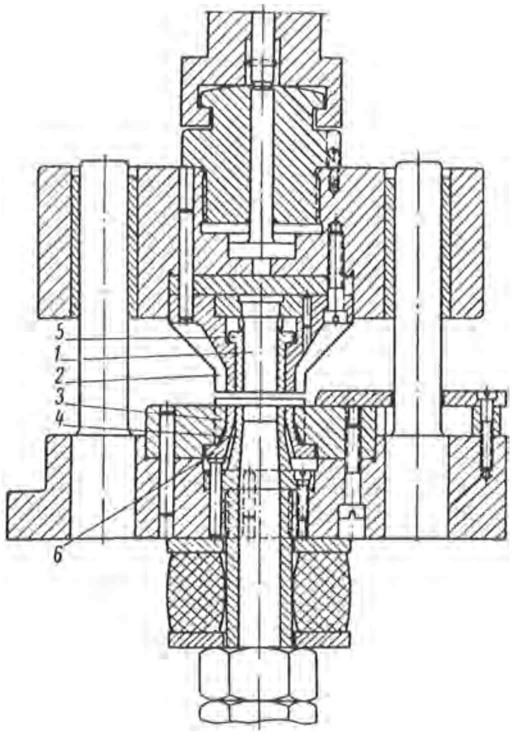

FIGURE 21. Die for the simultaneous blanking of the case middle and the bezel

Although this process requires the additional operations of lug bending and bezel ejection, this is more than compensated for by the considerable economy achieved in nonferrous metal.

Strap bars are an integral part of the case middle. Numerous bar designs exist and there are numerous methods of fastening the bars to the watch case. The design of the removable bar of the "Pobeda" watch case is shown in Figure 22. The spring (3), compressed by the plunger (2), is introduced into the drilled hole in the body (1). The hollow part of the bar is so necked that the clearance for the plunger is reduced to 0.03–0.06 mm.

As the bar body (1) is introduced into one lug hole, the plunger (2) is drawn to the left by pincers and compresses the spring (3). When the plunger end enters the second hole, the spring (3) presses the plunger against the lug wall. The distance between the shoulders is equal to the distance between the lugs.

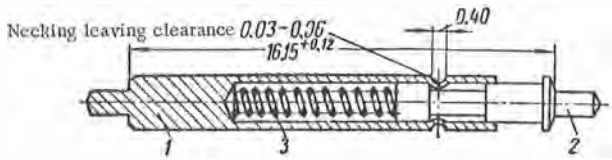

FIGURE 22. Strap bar of the "Pobeda" watch case:

1–body; 2–plunger; 3–spring.

Parts (1) and (2) are manufactured on Swiss-type automatic screw machines, while part (3) is manufactured on a special automatic machine.

THE CASE BEZEL

The bezel is a ring of weak cross section (Figure 2), and is therefore easily deformed. Its configuration and its low rigidity led to the use of a split manufacturing process (involving a sequence of roughing operations). The main operations are listed below.

The part is blanked from strip material by an Sh-04 compound die on a 20-ton crank press (first operation, Figure 23). The strip layout is a two-row chessboard arrangement and the blank deformation in the plane must not exceed 0.05 mm, while the ellipticity of the hole must not exceed 0.05 mm. The blanking is followed by stress relief, washing, burr removal, and repeat washing.

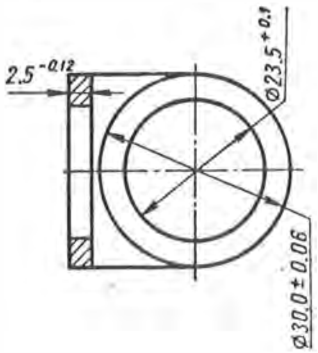

FIGURE 23. Bezel blank

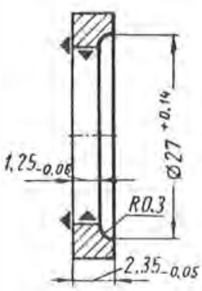

FIGURE 24. Facing and boring (second operation)

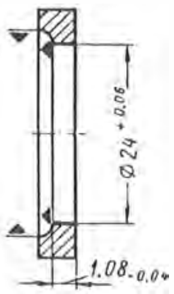

FIGURE 25. Facing and boring (third operation)

The blank is gripped in a chuck on a special lathe (Figure 24), one of its faces is faced, and a 27 mm diameter recess is machined (second operation). The opposite side is then faced, and a 24 mm hole is bored (Figure 25) on a special machine (third operation). The blank is then positioned according to the bored hole and its adjacent face in a special lathe. The outer diameter of the blank, its opposite face and the fitting shoulder are then turned (Figure 26) (fourth operation). The ovality of the 28 mm diameter fitting shoulder must not exceed 0.02 mm, according to the technical specifications for case assembly.

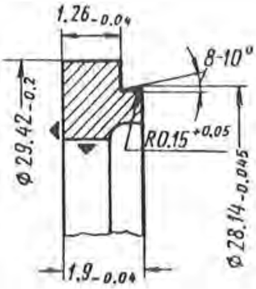

FIGURE 26. Turning the outside diameter (fourth operation)

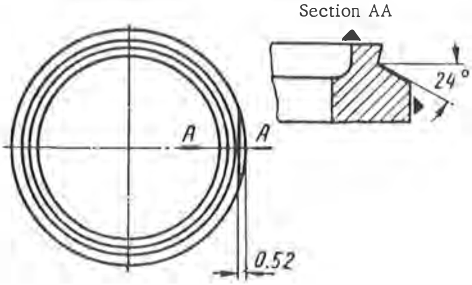

FIGURE 27. Milling a flat (fifth operation)

An inclined flat is then milled in a horizontal milling machine (Figure 27) (fifth operation). This is followed by the machining of the recesses for the crystal and dial and by chamfering (Figure 28) on a special lathe (sixth operation).

The crystal and dial recesses must be concentric relative to the fitting shoulder for the case middle, and the run-out of one bore relative to the other one must not exceed 0.03 mm. The bezel is then positioned by the recess, (Figure 29) on a special lathe and the tapered edge is turned (seventh operation). The outer surface of the bezel is then polished and buffed (prior to electroplating) (Figure 30) on the S-42 polishing machine (eighth operation).

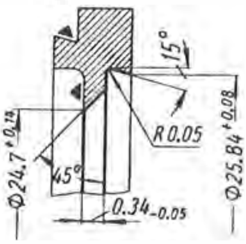

FIGURE 28. Boring for the crystal and the dial (sixth operation)

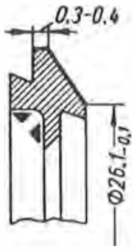

FIGURE 29. Taper turning (seventh operation)

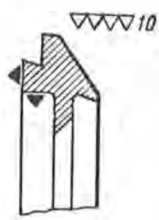

FIGURE 30. Outside-surface polishing (eighth operation)

The fitting dimensions of the bezel shoulder and the bore of the middle are machined to a tolerance of 0.045 mm. The negative allowance in the bezel-middle assembly can therefore vary within a range of 0.09 mm, while the value allowed by the specifications is only 0.05 mm. The middles and bezels are accordingly sorted into two groups.

The number of bezels blanked from strip material in the form of rings represents only 3 to 5% of the bezel-production program. Most of the bezel blanks have the shape of oval rings (Figure 20) or disks obtained as scrap in the blanking of the case middle (Figure 31). A hole is pierced in the 4 mm thick, 23.5 mm diameter disk, and it is then stress-relieved and twice expanded in a die, after which its shape and dimensions are identical with those of the bezel blanked from strip. Expanding reduces both the width and the thickness of the ring walls. The primary blank dimensions are determined experimentally.

FIGURE 31. Bezel blank obtained from middle-blanking scrap

The bezel is subjected to electroplating, after which it is assembled with the crystal. The crystal is blanked from a plexiglass strip 0.8–1 mm thick, turned and chamfered. The crystal is then given a convex shape in an electrically heated die (110–120°C) and pressed into the bezel by means of a press.

THE CASE BACK

The case back has a thickened flange, necessary to ensure its tight coupling with the case middle (see Figure 2). The back snaps onto the middle due to elastic deformation.

Backs are blanked from strip material and simultaneously drawn. The flange profile is then formed according to the fitting dimensions, and the inner and outer surfaces are polished and buffed.

The part (Figure 32) is blanked by a compound die in a crank press (first operation). The strip layout is a double-row chessboard arrangement and the final dimensions of the drawing punch and die are established during the testing of the die.

The back flange is formed in two upsetting operations (Figures 33 and 34) in toggle-lever presses of 100 to 125 ton capacity (second and third operations). The S-81A two-spindle semiautomatic machine (fourth operation) is used to face the flange and to machine the 27.46 mm diameter lip (Figure 35).

A flat is milled on the back (Figure 36) using a horizontal milling machine (fifth operation) and an angle milling cutter with the back held in a fixture. Several plants have recently begun to grind this flat in a special automatic machine, whose production rate is five times that of the milling machine.

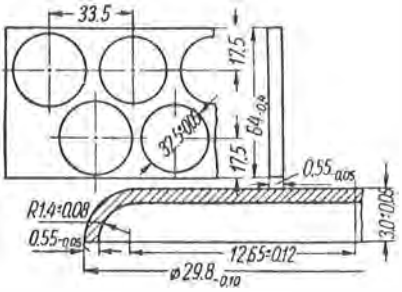

FIGURE 32. Back blank

A design is chased on the inside of the back (sixth operation) (Figure 37) on a special two-spindle semiautomatic machine (Figure 38). The back is held in a collet in the lower spindle of the machine. The mandrel with the abrasives-carrier is mounted in a collet in the upper spindle and the abrasive grains trace grooves on the back as a result of the lower-spindle rotation. The radial motion of the upper spindle corresponds to the transfer of the mandrel to the next sector of the back. The abrasive used is emery of grain-size 180 to 220. The spindles work simultaneously and the loading and removal of the back takes several seconds. The production rate of the machine is 2500 backs per shift. The circumference of the case back is buffed (Figure 39) on the S-42 machine by felt disks charged with a chromium oxide paste. The fitting dimension of the back is machined to an accuracy of 0.045 mm. Prior to assembly, the backs are sorted into two size groups according to the fitting dimension.

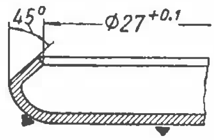

FIGURE 33. Preliminary forming of the case-back flange (second operation)

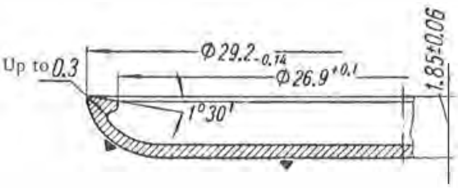

FIGURE 34. Final forming of the flange (third operation)

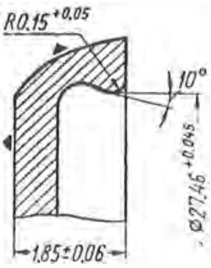

FIGURE 35. Facing and turning the flange (fourth operation)

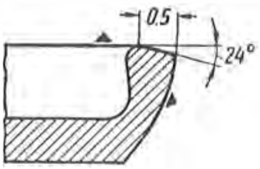

FIGURE 36. Milling a flat (fifth operation)

Chasing (diameter of decorative circles 4 to 5 mm)

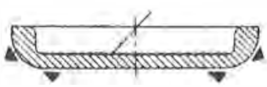

FIGURE 37. Chasing the inside of the back (sixth operation)

The case backs of waterproof watches have a more rigid section profile and are threaded into the case middle. A P. V. C. sealing ring seals the flange.

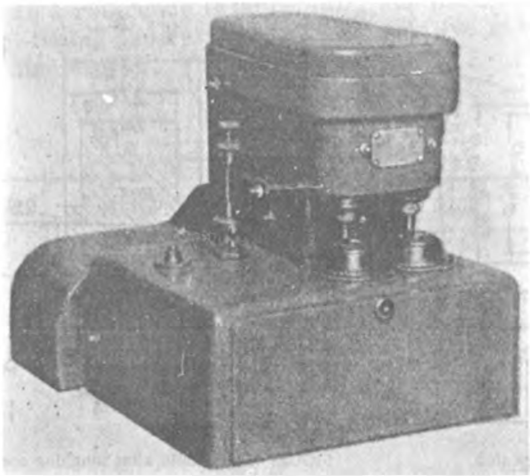

FIGURE 38. Two-spindle semiautomatic machine for chasing of back

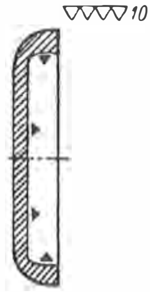

FIGURE 39. Buffing the circumference of the case back (seventh operation)

The manufacturing process for wristwatch cases described above requires very diversified equipment and a relatively high labor expenditure for a relatively low manufacturing accuracy. Design and production engineers are therefore striving to develop improved methods for machining the case parts, which would reduce both the labor expenditures and the material requirements. Some such methods are: pressure die-casting, precision casting, and stamping in hot or cold state. The blanks obtained must be such that the only mechanical operations required are the finish operations for the fitting dimensions, which have narrow tolerance.

THE CASE MIDDLE OF POCKET WATCHES

The case middle of pocket watches has concentric projections and recesses in which the watch movement, the bezel and the back are fastened.

NMTsS 63-18-2 nickel silver, which is used in the manufacture of the middle is not sufficiently plastic for expanding operations. The middle is accordingly blanked out of a 4 mm thick strip as a ring (Figure 40). The blanks are degreased, stress-relieved and washed, and then rough-machined on metal-cutting machines to produce a ring having the shape shown in Figure 41.

While in wristwaches the winding-stem hole is obtained in one operation, as many as 18 operations are involved in making the winding-stem hole in pocket watches. The operations are as follows: machining the middle to take the pendant, brazing-on the pendant, cleaning the brazed spot and sizing the middle and pendant, machining the hole and the projections for the winding crown and bow.

The axis of the hole ($1.38^{+0.04}$ mm diameter) (Figure 42) must be parallel to the plane of the fitting projection for the movement and at a distance of $1.10^{\pm 0.02}$ mm from it. The noncoincidence of the hole axis and the central axis of the middle must not exceed 0.05 mm.

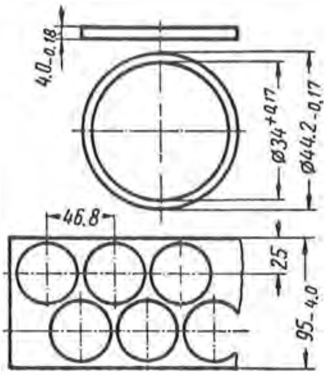

FIGURE 40. Blank of pocket-watch middle

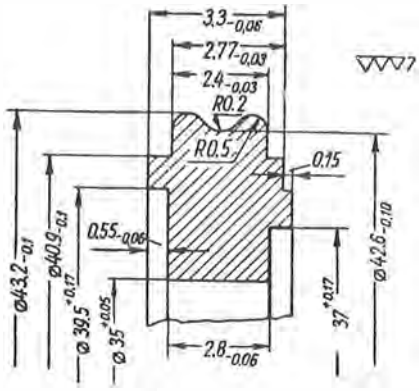

FIGURE 41. Middle after roughing operation

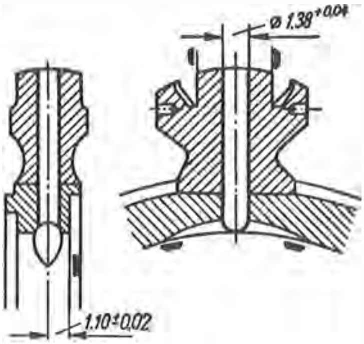

FIGURE 42. Drilling 1.38 mm diameter hole

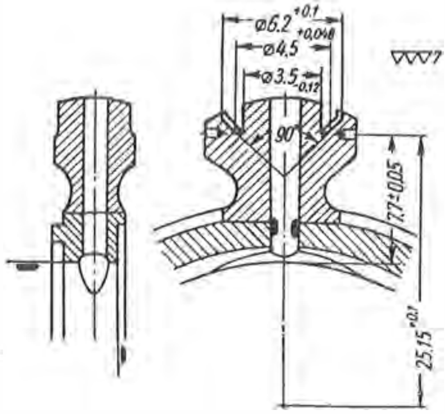

FIGURE 43. Milling the crown recess in the pendant

The drilling and reaming of the hole are followed by milling of the recess for the winding crown in the pipe (Figure 43), using a hollow mill on an S-2 vertical milling machine.

The Ø 2.2 mm recess is then bored by a counterboring tool to a depth of 2.7 mm (Figure 44), and the burrs are removed from the pendant face and the milled contour by a compound milling cutter.

The middle thus prepared is then subjected to the finishing operations: turning the fitting projections for the bezel and back, and machining the inner recesses for the watch movement.

The fitting projections for the bezel and back are turned on the S-81A semiautomatic machine in two consecutive operations (Figure 45).

The internal fitting surfaces of $36^{+0.08}_{+0.03}$ and $35.85^{+0.10}$ mm diameter are also bored on the S-81A semiautomatic machine, the bezel-fitting projection serving as a reference (Figure 46). The maximum permissible runout of the bezel-fitting projection (41.2 mm) relative to the movement-fitting bore (36 mm diameter) is 0.05 mm.

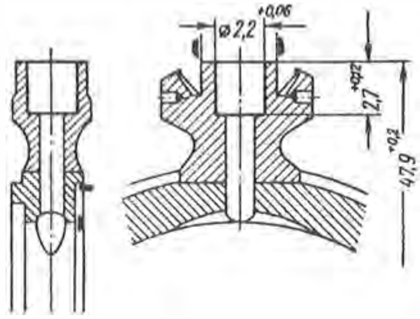

FIGURE 44. Facing and boring the crown hole with a counterboring tool

The burrs in the winding-stem hole are removed manually after the movement-fitting bore is completed. The middle is then chromium-plated.

The bezel and the case back of pocket-watch cases are machined in the same manner as the corresponding wristwatch parts. The pendant bow is manufactured from wire by coiling it on a mandrel in a close spiral and cutting with a milling cutter.

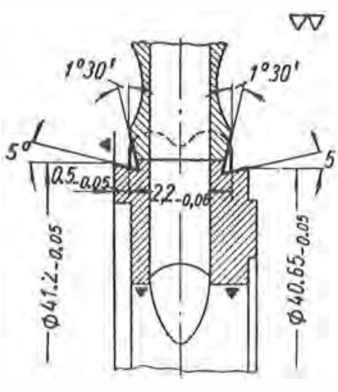

FIGURE 45. Turning the projections of the middle

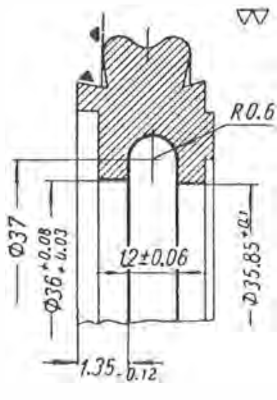

FIGURE 46. Internally machining the middle

Well-polished cases made of gold or gold-plated nickel silver have an aesthetic appearance which is preserved for a long time. Gold, as is well known, is not tarnished by atmospheric air, and resists the corrosive action of water, bases and acids (aqua-regia excepted). Gold cases usually have an attractive shape, especially those for ladies' wristwatches where the case shape blends harmoniously with the shape of the gold bracelet.

Cases are usually made of gold of 583 ‰ or 750‰* purity (meaning that the alloy contains 583 or 750 parts of pure gold, the remainder being copper and silver in various proportions). More silver in the alloy imparts a bright appearance, while increasing the proportion of copper gives it a reddish shade. Pure gold is very soft and malleable, and the copper and silver are added to it in order to give the gold alloy the necessary hardness. Fourteen-carat gold has a hardness of R_B 87 to 90 and resists wear, this being very important both for the conservation of the lustre and for the preservation of the case weight.

The technology of gold-case manufacture is similar to that used in the manufacture of nickel-silver cases with modifications in the cutting conditions. The most complex operation is the brazing of the case lugs. The brazing alloy should be of the same carat number as the case, and brazing should be carried out at a temperature near the melting point of gold. Local heating is used to prevent the deformation of the part and the brazing is performed in a protective medium to preserve the uniform color of the case.

The technical specifications for the manufacture of gold cases specify that the gold chips must be collected after each operation. The machines are equipped with special plexiglass shields and the washing and cooling liquids are specially filtered.

Cases are polished on standard machines (of the S-42 type) by felt disks charged with chromium-oxide paste.

In order to reduce the quantity of gold chips, the case is so shaped that it can be obtained by swaging.

Small-size ladies' watch cases usually have such a shape and their weight is between 3 and 8 g, while the weight of men's wristwatch cases is between 11 and 20 g. Pocket-watch cases, with one or two backs, weigh between 25 and 40 g, and sometimes as much as 50 g.

The production of gold-plated cases in very large quantities has recently begun abroad, the object being gold economy and price reduction. The base used is nickel silver or special brass and the gold plating can be produced by thermal, galvanic or mechanical methods.

The thermal method is the most widely used, as it produces a strong bond between the gold alloy and the base metal. A 300×60×20 mm nickel-silver or special brass plate is sandwiched between two gold-alloy plates of at least 14-carat gold content and having dimensions of 300×60×3 and 300×60×1.5 mm, respectively. A special paste is applied between the plates. Steel plates of 300×60×20 mm each are added and the entire stack is compre-sed by 4 to 5 clamps and placed in a gas furnace, where it is heated to a predetermined temperature. The clamps are adjusted several times during the heating process, which lasts for 35-40 minutes. A surface diffusion of one metal into the other occurs during the heating and when the process has been completed the ensuing bimetallic strip is rolled in several passes,

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* [Corresponds to a purity of 14 and 18 carat, respectively.]

with intermediate annealing for which purpose the strip ends are connected to terminals, and the strip is heated by electric current to red incandescence. The strip surface is coated with an ochre paste to prevent oxidation.

The completed rolled strip consists of three rigidly bound layers: outer layers of gold 20μ and 10μ thick, and a core of 0.35 to 0.5 mm thickness. Stamping and other mechanical operations similar to those used in producing gold cases are performed on the strip. Blanks are annealed after stamping operations in furnaces with a neutral medium.

The gold layer thickness is reduced from its original 20μ to 10μ on protuberances, acute angles and transitions which result from drawing and forming operations. The layer thickness on these features is sometimes as little as 3 to 4μ, which corresponds to 3 to 4 years wear. Bright points appear at the spots where the gold is thin (the nickel silver shows through), and, in order to obtain a uniform hue, the case is galvanically gold-plated (1–2μ). The galvanic layer is rapidly worn, however, and hues appear on the watch case. To avoid these problems sharp transitions should be avoided in gold-plated cases and they should have a streamlined form.

The quantity of gold used in a thermally-plated case is only 10 to 12%, the quantity required for a solid-gold case. It is, however, difficult to determine the exact amount of gold in a case gold-plated by the thermal method. Wristwatch cases have sometimes backs made of stainless steel. The middles of such watches are so designed as to make the back invisible from the side. The amount of gold required for a watch of this type is only 0.4 g. A variation of the thermal-plating process involves the separate blanking of nickel-silver and gold parts which are then soldered with tin or bound together by means of a special compound, after which they are subjected to the subsequent operations. This method has the advantage that the gold scrap is separate from the nickel-silver scrap and so can be salvaged. The scrap from the bimetallic strips has to be subjected to etching to remove the nickel silver so that the gold can be recuperated.

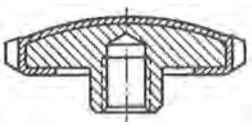
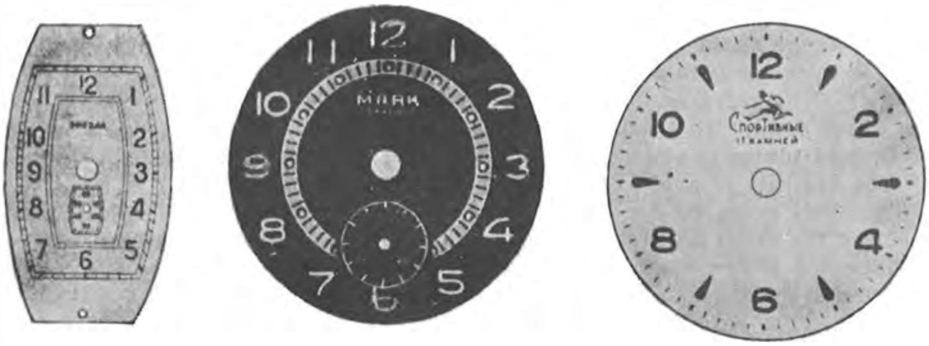


FIGURE 47. Winding crown with gold envelope

Galvanic gold-plating of watch cases is not widely practiced because galvanic baths only work satisfactorily with pure gold, and a pure-gold coating is of low durability. Electrolytes containing 14- and 18-carat gold are unstable in operation and produce a low-quality coat. The thickness of the gold layer produced by such baths does not exceed 5 to 7μ and repeated plating operations are therefore necessary in order to obtain a 20μ thick layer.

A mechanical gold-plating method involves closely fitting a gold foil to the case and the winding crown. This requires a larger amount of gold than that required by the thermal or galvanic methods. This mechanical method is now being used only for coating the winding crown, to which end gold foil is used, 0.05–0.10 mm thick and having the same color and the same carat number as the case (Figure 47).

The dials of wrist- and pocket-watches are made of L-62 brass or L-90 tombac. Their design and finish are very diverse. The dial field can be white (silvering), pink (alloy gilding), or black (oxidation or black-nickel plating). The marks on the dial may be flush or raised and include the watch-scale figures or the symbols which replace them, and the divisions of the minute and second scales with incomplete (or completely lacking) numbering (Figure 48). The figures are printed by using printer's ink or luminous paste, or are embossed in dies (raised figures).



a b c

FIGURE 48. Watch dials:

a–"Zvezda"; b–"Mayak"; c–"Sportivnye".

The process of dial manufacture consists basically of the following operations: blanking, soldering the feet, recessing, preparing the surface for coating (degreasing and etching), silvering or gilding, varnishing, printing and drying.

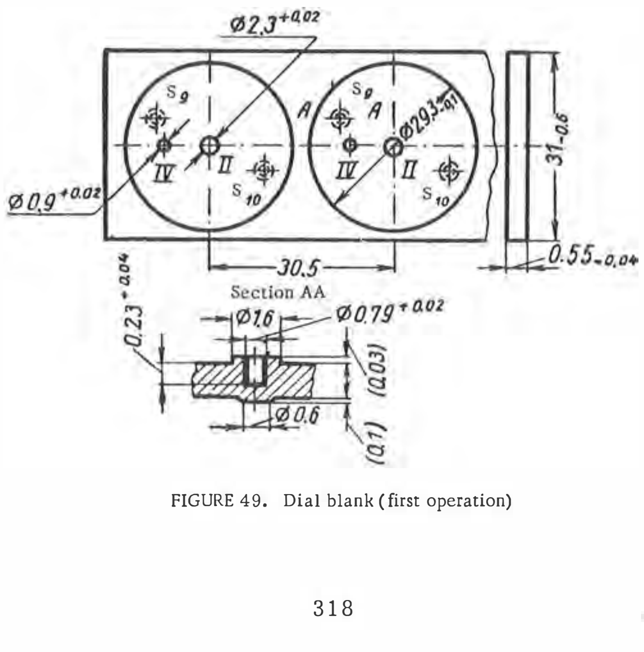


FIGURE 49. Dial blank (first operation)

For example, the dial blank for caliper K-26 wristwatches is blanked with two through holes for the axes of the hands, and two blind holes for the feet (Figure 49). The operation is performed on a 15-t crank press by a compound die (Sh-04). The permissible run-out of the outer diameter relative to the central hole is 0.02 mm.

The blank is ground on the S-29 machine, the object being the leveling of its face, after which it is degreased in an organic solvent.

Two feet are pressed into the blank and soldered using PSR-45 silver solder (Figure 50). The ring-shaped solder preform is placed on the dial foot; the soldering location is moistened with borax; and the foot is soldered in a gas burner. In some plants the feet are welded on an electrical welding machine.

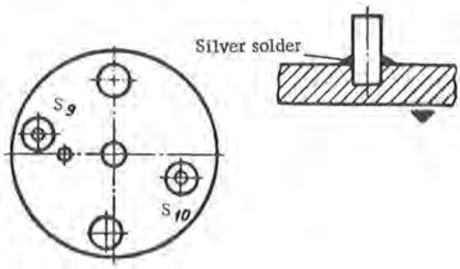


FIGURE 50. Soldering the feet

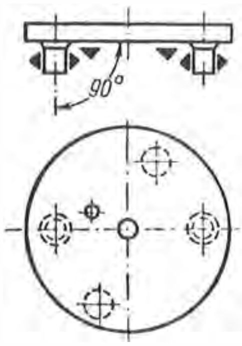


FIGURE 51. Sizing the feet

The soldered joint is then cleaned, and the feet and the dial face are straightening (Figure 51). The cleaning is performed by means of a hollow mill in a vertical drilling machine, while the straightening is performed on a special semiautomatic machine. The dial-face flatness is tested using a ruler.

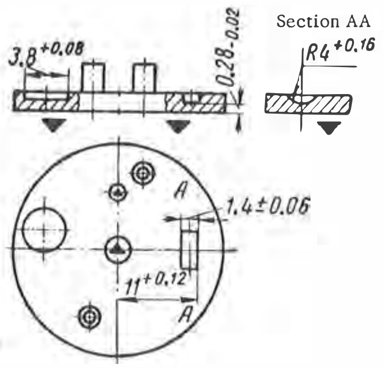


FIGURE 52. Machining the recesses for the winding pinion and the balance cap

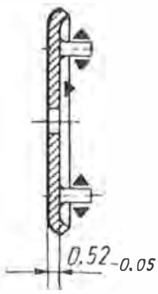


FIGURE 53. Polishing the dial face

The slot for the winding pinion is then milled, and the recess for the balance cap bored on horizontal and vertical milling machines, respectively (Figure 52). The machines are adjusted using an adjusting or positioning template, and the two holes for the hands serve as a reference.

After the edges are bent, the dial face is ground and polished (Figure 53) on the S-42A machine by felt disks charged with emery paste of grain-size 280 to 320 and with chromium-oxide paste. The surface-finish quality must be grade $\nabla\nabla\nabla\nabla$ 10, and no scratches, dents, or other defects visible under a 5× magnifying glass are permitted.

The dials are washed before inspection in four baths with "Galosha" brand benzine (GOST 443-41) and are bushed using a soft-hair brush.

Dials which pass inspection move on to the next operation, which is the boring of the seconds-hand recess (Figure 54). The operation is performed at a high tool-feed rate of 0.10–0.15 mm/rev in order to obtain a clean Archimedean spiral on the recess surface (Figure 54, b). The central part of the dial field is sometimes faced, using the feed rate mentioned, in order to obtain an aesthetic design.

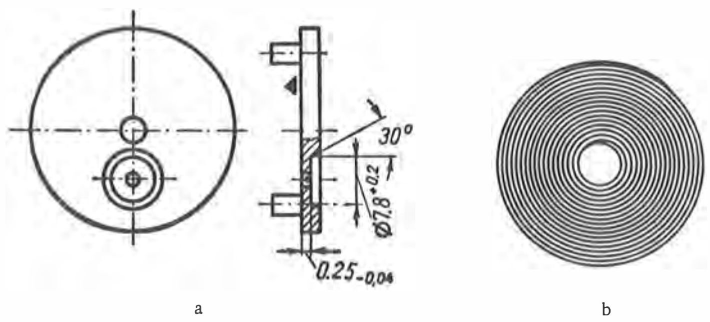


FIGURE 54. Seconds-hand recess

The blank is again washed in four benzine baths and is then subjected to silvering. Silver plating is preceded by electrolytic degreasing, washing in very hot and in cold water, and brushing of the face in order to remove the oxides and give it a uniform hue. The blank is then suspended from a frame and charged into the silver-plating bath where a 1.5 to 2 μ thick silver layer is deposited. Three baths wash off the remainder of the electrolyte, and the dials are then rinsed in cool running water after which they are spread, faces down, on tissue paper for drying.

Varnishing is a critical operation, as it must protect the silver surface against the effects of air and so preserve its appearance for many years. The varnish must resist the action of sun and that of other light sources. It must be colorless, and must not distort the dial field or change its color. The thickness of the varnish coat must be 5–6 μ, so as to be invisible to the eye.

These requirements are satisfied, to a certain extent, by the BMK-5 resin, which is soluble in amylacetate and in acetone. The dials are dried before varnishing by consecutive dippings in three acetone baths and are then varnished in a centrifuge, and dried at 40–45°C in a glass cupboard in order to prevent dust from setting on them.

The figures, inscriptions, symbols, and divisions are printed on the dials using bench presses and india-rubber cylinders (Figure 55).

A die carrying printer's ink in its recess is mounted on the press table. The dial is mounted on a support at a distance l from the die. The rubber cylinder is first lowered onto the die where it takes a negative imprint of the dial scale. The table is then displaced a distance l and the cylinder descends on the dial and prints the entire scale. The printing is performed in two stages, with intermediate and final drying at 40–45°. The ink must be laid in a uniform layer, 4 to 5 μ thick, without discontinuities (gaps) or leaks. The printing is inspected under a 5× magnifying glass and the dials are then varnished again with the same BMK-5 resin and dried. The finished dials are packed in stacks to prevent damage during transportation and storage.

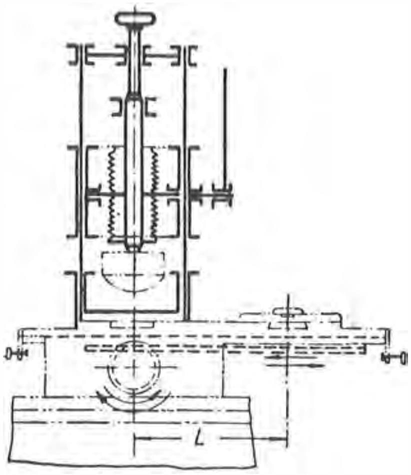


FIGURE 55. Press for dial printing

Dials with a black glossy field and white or luminous symbols are manufactured by a process which differs from that described above in that the dials are dipped into baths containing special mixtures (see Chapter Nine).

The printing of figures and symbols with luminous paste is performed on a pneumatic printing set (Figure 56). Thick luminous paste is poured into the upper cylinder of the set. A lid with rubber padding closes the cylinder and air is supplied from the side. A die with 7 to 10 small through holes in each figure (symbol) contour is mounted in the lower part of the cylinder. The dial, with the figures and signs printed on it in white ink, is placed on the lower table. The table is fed manually under the die, and then lifted pneumatically and pressed against the die. Air pressure is simultaneously fed to the cylinder with the luminous paste. The paste passes through the die holes and is deposited on the dial in the form of the figures and symbols in the die. The pressure is held for several seconds and the table is then lowered. This machine has a production rate of 1200 to 1500 dials per shift, independently of the number of figures and symbols to be printed on each dial.

The manufacture of dials with either pink mat or embossed silver field, and gilded relief figures is different from the processes described above.

The raised figures and field are embossed in one stroke on knuckle or frictional presses. The recesses for the figures and symbols are embossed in the die by a smooth punch. The figures are 0.25 to 0.35 mm high.

After embossing the dials are annealed, etched and trimmed on the outer contour.

Watch hands are made of polished 10M low-carbon steel strip or from polished LS63-3 brass strip. Hands, like dials, are very diverse in shape and finish (Figure 57). A different hand shape usually corresponds to each dial shape (Figure 58). Hands are classified into two types – blind and with windows (skeleton).

Hands with a drawn hub are blanked in a die by the scrap-blanking method (Figure 59) on an automatic press. Minute hands without hubs are directly blanked. The manufacture of hour and minute hands is identical in other respects.

FIGURE 56. Machine for printing dials with luminous paste

The blanked hands are straightened on a steel plate, and then carburized, hardened and tempered in order to make their surface hard and elastic.

C a r b u r i z i n g is used when a combination of a tough core and high surface hardness is required. The carburizing of hands made of grade-10 steel is conducted in electric furnaces; 600–800 pieces are placed in a container together with the carburizing compound (95% charcoal and 5% soap powder); and the container is closed hermetically.

a b c

FIGURE 57. Hand shapes

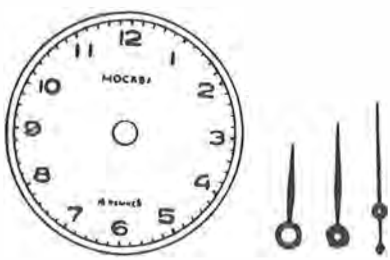


FIGURE 58. Dial and hands

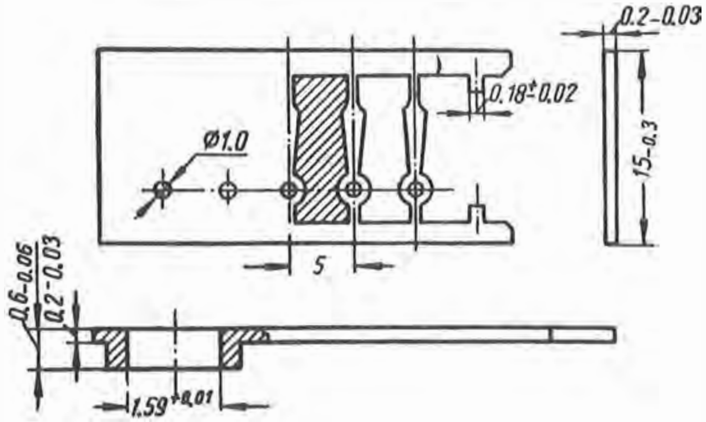


FIGURE 59. Blanking hands by the scrap-blanking method

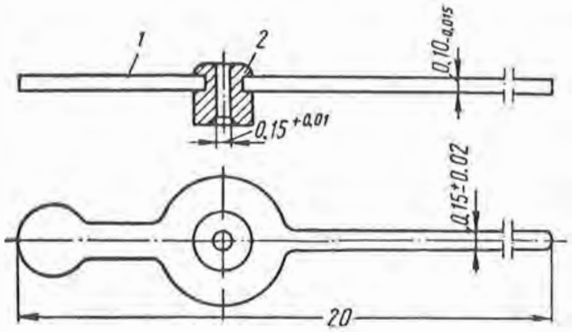


FIGURE 60. Seconds hand

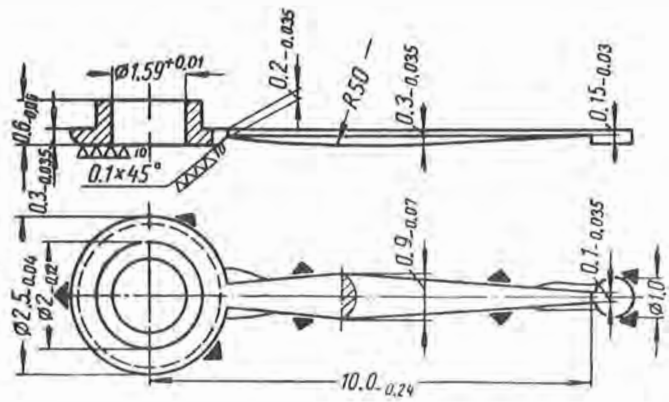


FIGURE 61. Hand with a spherical surface

The hands are held in the furnace at 800 to 820°C for 45 to 50 min and are then quenched in oil either directly or after air-cooling and reheating.

Tempering is performed at temperatures between 350 and 480°C producing a hardness between R_C 36 and R_C 46. The exact temperature depends on the type of hand, and the holding time is between 40 and 60 min.

Heat treatment is followed by random testing (bending and breaking) for the determination of the elastic properties and microstructure. The hands are next drum-tumbled with abrasives and leather scraps, and washed in organic solvents (Standard N-3418, Appendix 10). Polishing, performed on S-42A machines by felt disks charged with grinding and polishing pastes follow.

The well-polished and degreased hands are placed on a stainless-steel support and are charged into an electric crucible furnace, where they are held for 2–3 min at 370–390°C. The hands are under observation and the moment a blue annealing color appears, they are quickly withdrawn from the furnace, shaken off the support onto a piece of paper and cooled in air. Blueing and cooling is followed by washing in a soapy solution, after which the hands are rinsed in cool running water and in alcohol, and dried in a cupboard.

The seconds hand is composed of the hand proper (1) and the hub (2) (Figure 60). The hand (1) is made of 10T steel by a process identical with that for the manufacture of the minute hand and, when finished, is fitted on a brass hub and staked. The operation is performed on a bench press.

Hour and minute hands having a convex surface (Figure 61) are formed and trimmed after blanking. Steel hands which have to be coated with various paints, luminous paint or with gold, are subjected to the entire cycle of operations described above, beginning with the blanking and ending with face polishing. The final operations depend on the particular requirements of the design drawing and the technical specifications.

Chapter IX

FINISHING OPERATIONS

Finishing operations occupy a prominent place in watch production. Watch-movement parts are ground, lapped and polished in order to reduce friction and increase their resistance to corrosion. External parts (cases, dials and hands) are subjected to finishing operations designed to give them an aesthetic appearance and to make them resistant to light, wear and corrosion. The complex of finishing operations includes grinding, lapping and polishing as well as electroplating and chemical and varnish coating. Steel parts of the watch movement are subjected to heat treatment (hardening and tempering) before being ground and polished. Hardening and tempering conditions for typical watch parts are given in Table 1. Parts made of non-ferrous alloys are subjected to additional mechanical, chemical and electrochemical processing before being coated.

TABLE 1

Hardening and tempering conditions for typical watch parts

Part	Grade of steel	Hardening			Tempering		
		temperature, °C	time, min	hardness, H_{R_C}	temperature, °C	time, min	hardness, H_{R_C}
Balance staff	U10A	780—790	7	63—65	180—190	12	59—61
Barrel arbor	U10A	780—790	8	63—65	200—210	12	56—58
Cannon pinion	U10A	780—790	7	63—65	350—400	10	49—52
Winding wheel and keyless wheel	U10A	780—790	8	63—65	200—210	20	56—58
Escape wheel	U10A	780—790	7	63—65	280—290	10	53—55
Pallet lever	U10A	780—790	6	63—65	280—290	7	53—55
Regulator	U10A	780—790	7	63—65	280—290	10	54—56
Hour-setting and winding lever	U10A	780—790	7	63—65	200—220	10	56—58
Pinions	U7AV	800—820	6	62—64	280—300	8	52—55
Screws	U7AV	800—820	5	62—64	330—340	8	47—50
Pallet arbor	U7AV	800—820	5	62—64	200—210	10	56—58

GRINDING, LAPPING AND POLISHING OF STEEL PARTS

The working surfaces of steel parts, such as the journals of pinions and staffs (must have, at least, a class 12 finish in order to reduce friction in the watch movement to a minimum. The outer surfaces of the parts (the faces of screw heads, the upper faces of the keyless and escape wheels, the regulators, etc.) must be finished to surface-quality class 11–12 at least, in order to give the parts an aesthetic appearance and to make them corrosion-resistant.

Grinding, lapping and polishing of the parts after hardening and tempering gives them the surface-finish quality required. The first two are preparatory operations which precede polishing and impart a class 8 or 9 surface-finish quality.

Pinions and staffs turned in automatic machines have a class 8 or 9 surface-finish quality and therefore need no additional stages prior to polishing.

Certain flat parts, such as keyless wheels, hour-setting and winding levers, are ground in order to level their faces and remove burrs resulting from blanking.

Polishing removes microroughness 0.25 to 3.2 μ high from machined surfaces.

Polishing is classified as being dimensional or decorative. Dimensional polishing has the dual aim of providing a class 11 to 13 surface finish and of bringing the dimensions within the required tolerances. Decorative polishing, or buffing, is applied to impart an aesthetic appearance to the parts. Although no dimensions are specified in decorative polishing, the thickness of the metal layer removed must lie within the tolerance limits on the part dimensions.

The grinding, lapping and polishing methods used in watch production are extremely diverse and depend both on the dimensions and shape of the machined part and on surface-finish requirements. The abrasives used are also very diverse.

Lapping and polishing flat steel parts. Flat parts are lapped and polished on the S-15 two-spindle vertical machine (Figure 1).

The machine consists of a base, inside of which an electric motor is mounted, a bed with a round table and control mechanism, and a support which carries two spindles. The electric motor drives the round table and the machine spindles (Figure 2) through gears (1–2–3–4–10–11–12–13) and (1–2–3–4–5–6–7–8–9) respectively.

The gears (11) and (13), fitted freely on a shaft, transmit rotation to the round table through a draw key, by means of which two speeds of rotation can be imparted to the machine table.

The duration of operation is adjusted by means of a special device. The gears (14) and (17), which are part of a planetary train, are mounted on the same shaft with gear (10). The planet gears (15) and (16) are rigidly interconnected by a bushing and fitted on a shaft fixed to gear (10). One revolution of gear (10) corresponds to 0.00037 revolutions of the shaft carrying the spiral gear (18), and therefore to 0.00037 revolutions of the shaft carrying the spiral gear (19). If $n = 90$ rpm for gear (10), gear (19) will revolve at 0.033 rpm (1/30 rpm), as can be calculated using the planetary-transmission formula for one revolution of gear (10)

$$i = 1 - \frac{53 \cdot 51}{52 \cdot 52} = 0{,}00037.$$

The shaft which carries gear (19) also has a jaw clutch (20), on whose left element the pin (21) is fastened. When shaft and clutch revolve, the pin (21) approaches the stop (22) and lowers it. The stop (22) is thus made to act on a microswitch which stops the electric motor, and thus the machine.

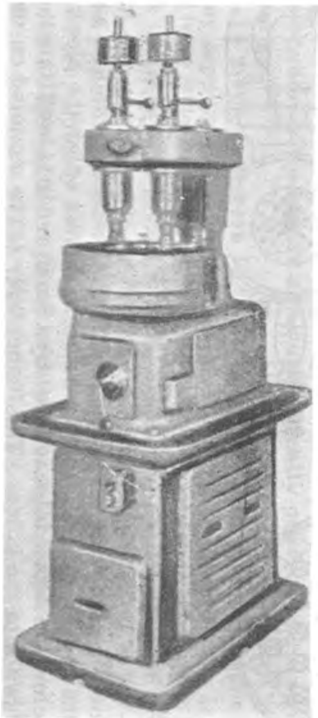


FIGURE 1. S-15 two-spindle flat-surface lapping machine

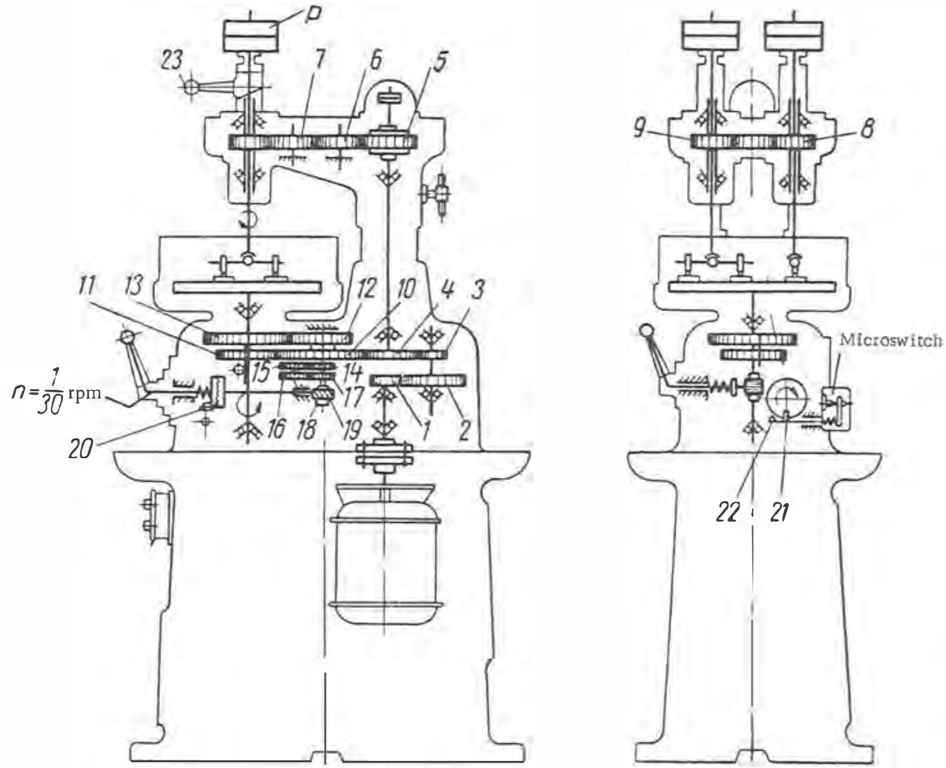


FIGURE 2. Kinematic scheme of the S-15 machine

The time of continuous operation of the machine can be adjusted between 0.5 and 30 min by suitably positioning the clutch jaw with the pin (21) relative to stop (22).

Technical data, S-15 machine

Table diameter, mm	240—320
Maximum block diameter, mm	50
Table speeds, rpm	60, 120
Spindle speed, rpm	192
Distance between spindles, mm	150
Number of blocks set simultaneously	4
Electric motor	1 kw 1440 rpm

The parts to be lapped and polished are fastened to the blocks using rosin or shellac. The blocks are cast-iron disks 40 to 50 mm in diameter and 2.5 to 6 mm thick, having recesses of various shapes into which the parts to be machined are placed.

The design of a block for lapping and polishing of screw heads is shown in Figure 3. There are spaces for 100 to 500 screws in the block. The screw shank fits into a hole, and the head is supported on the flat or conical face of the hole. The screws are loaded into the blocks by the S-14 machine (Figure 4).

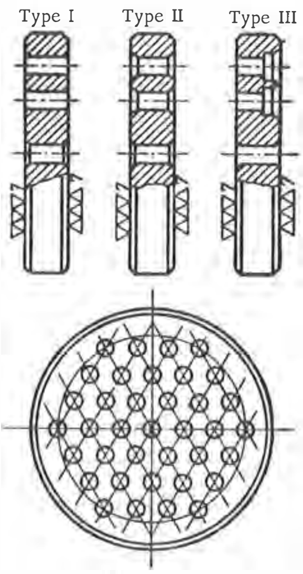


FIGURE 3. Holding block for lapping and polishing of screw heads

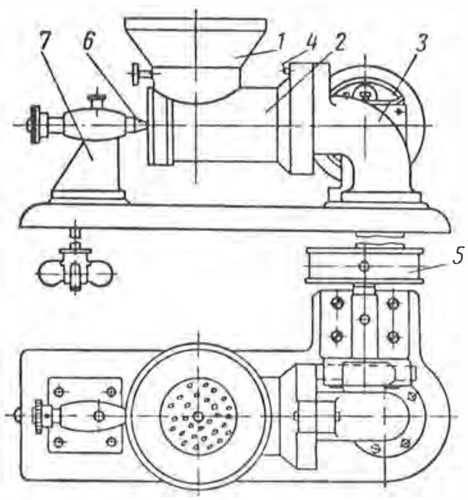


FIGURE 4. S-14 machine for setting screws into holding blocks

The block is placed in the machine funnel (1) and screws are poured from above. The funnel vibrates, and the screw shanks enter the block holes. The air below the block is evacuated by a fan in order to facilitate the setting of the screws into the holes. The funnel body (2) is mounted on the connecting arm (3) and held in a vertical position by the pin (4). A reciprocating motion is imparted to the funnel body by an eccentric shaft driven by pulley (5), and by the spring of the supporting center (6) placed inside the head (7). The machine head (7) and the connecting arm (3) are fastened to the machine bed.

Pulley (5) revolves at 145 rpm. A block is filled in 0.5 to 2 minutes. After the machine has stopped the funnel body is drawn back to the left, released from pin (4), rotated 90°, and the block removed. The holes which remain empty are filled with screws manually.

Shellac or rosin is then poured onto the block. The block is first heated on an electric heating plate till the shellac (or rosin) melts, and then the screws are pressed against the block by means of a press. After the blocks cool down, they are mounted on the S-15 machine. Fastening by means of shellac or rosin causes no deformation of the parts.

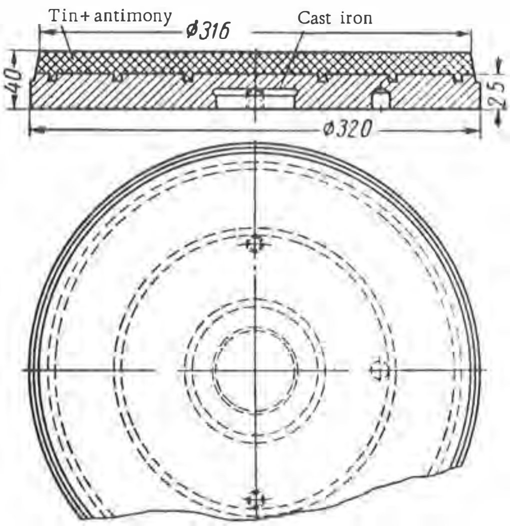


FIGURE 5. Polishing disk used in the S-15 machine

The blocks are mounted on the round table of the S-15 machine and are pressed down by weights placed on the upper ends of the spindles. A driver bar with two pins is fastened to the lower end of each spindle. The conical extremities of the pins fit the central holes of the blocks and press them against the table. The blocks are automatically positioned relative to the table plane.

The S-15 machine uses a finish-faced cast-iron disk of hardness 120 to 150 H_B for lapping. A layer of abrasive paste is applied to the lap (see Table 2).

A disk made of a 99% tin 1% antimony alloy is used for polishing (Figure 5). A layer of chromium oxide or diamantine* paste is applied to the disk.

Wooden polishing disks made of beech or lime are also used. Their flatness, however, quickly deteriorates, the block is pressed into the wood, and as a result the polished parts have burrs at the edges.

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* [See Table 2, Sect. 3.]

The weights on the upper end of the spindle transmit the required pressure to the block during lapping. One weight is sufficient in polishing, and it can even be dispensed with since the weight of the spindle and driver bar is often sufficient.

Two separate machines, at a distance of 1 to 1.5 m from each other, are used for the lapping and polishing operations in order to prevent abrasive grains from falling on the polishing disk. The blocks must be carefully cleaned of abrasives and washed in gasoline after lapping. Polishing is as a rule performed in two operations (preliminary and final). The lapping and polishing pastes, and the materials used for fastening the parts to the blocks, are selected in accordance with the configuration of the parts (see Table 3).

Shellac ensures a stronger bond between the parts and the block than does rosin and it is therefore used for pressures of 2.0 kg/mm^2 and above.

TABLE 2

Lapping and polishing pastes (compounds)

Paste characteristics	Paste type		
	A	B	C
1. Emery paste (for lapping)			
Emery, %	64	95	—
Grain size (grit), μ	M-28	M-20	—
Stearin, %	36	—	—
Lard, %	—	2.5	—
Kerosene, %	—	2.5	—
Surface-finish class	8—9	9—10	—
2. Chromium-oxide paste (for polishing)			
Chromium-oxide, %	67	60	66
Grain size (grit), μ	M-3.5	M-3.5	M-3.5
Stearin, %	13	—	29
Paraffin, %	13	—	—
Oleic acid, %	5	—	5
Graphite, %	0.2	—	—
Lard, %	—	—	—
Industrial fats, %	1.8	—	—
Kerosene, %	—	20	—
Surface-finish class	11—12	12—13	13
3. Diamantine paste (for polishing)			
Diamantine (leuco-sapphire or monocorundum), %	—	—	75
Grain size (grit), μ	—	—	M-3.5
Beeswax	—	—	25
Surface-finish class	—	—	13—14

Lapping and polishing conditions. During the operation of the machine, when the table and spindles revolve simultaneously, the block carrying the parts performs complex motions relative to the lap, as a result of which a uniform layer of metal is removed from parts both near and far from the block center. The lapping speed varies between 0 and 3 m/sec.

The same process conditions are used for lapping and polishing parts made of different grades of steel. The machining (basic) time depends on the area of the parts to be machined and on the allowance. In practice, the machining time is calculated on the basis of standards established in the watch plants. A table for calculating the lapping time for steel parts with 0.02 mm allowance is given in Appendix 6. The auxiliary time is also determined on the basis of standards.

TABLE 3

Lapping and polishing pastes (compounds)

Types of parts	Pressure, kg/mm^2		Material used for fastening the parts to the block	Lapping pastes	Polishing pastes
	lapping	polishing			
Screws, ratchets, regulators, caps, etc.	1–2	0–5	Rosin	Emery paste— type A	Chromium-oxide paste— type B
Escape wheels, pallet levers, etc.	2–3	0–5	Shellac	Emery paste— type B	Chromium-oxide paste—type B

An allowance between 0.05 and 0.20 mm is fixed for (flat) surface lapping, and the allowance for preliminary and final polishing is between 0.01 and 0.02 mm.

The deviations in the dimensions of parts polished on the S-15 machine do not exceed 0.01 to 0.02 mm, and therefore, in certain cases no particular allowance is established for polishing and the decrease in dimensions is at the expense of the final-dimension tolerance.

The operation of the S-15 machine is started by turning the handle (23) (see Figure 2). This lowers the spindles so that the ends of the driver-bar pins penetrate into the conical recesses in the work blocks and press the blocks against the table. The electric motor is then switched on, and the spindles and table begin to rotate. Paste is applied periodically by hand.

After the lapping, the spindles are lifted, the blocks are removed, cleaned of abrasives, and the height of the parts is measured by means of a dial gage. If the dimension is larger than specified, the blocks are again loaded into the machine, and the parts are lapped again.

Surface-finish quality after lapping and polishing is inspected visually using a magnifying glass (5×). A microscope (16×) is used in some cases.

After the polishing, the block with the finished parts is dismantled.

Polishing Pinion Teeth

After milling, pinion teeth have a class 8 or 9 surface-finish quality which is raised to class 11 or 12 by polishing.

The pinion teeth, which have a hardness of 52 to 55 H_{R_C} after hardening, are polished on the S-5 (Figure 6) or the S-83 machine with type A chromium oxide applied to the beech disk on the machine.

The polishing disk (1) of the S-5 machine is mounted on the spindle (2) of the rocker arm (3). The pinion is freely placed on its journals or projections in the steady-rest (4), which is held between centers on the heads (5) mounted on slide (6).

The polishing disk has a spiral flute along its circumference. When the rocker arm is lowered, the flute meshes with the pinion teeth and the pinion rotates about its axis as the disk rotates. If the length of the teeth is more than 2 mm, a reciprocating motion is imparted to slide (6) by the connecting rod (7) and the crank (8). A belt is slipped over pulleys (9) and (10) to provide power for the reciprocating motion.

The inserts for the steady-rest are made of carbide and are brazed to the rest with copper (Figure 7).

The beech polishing disk wears rapidly. The flutes in the disk are cut directly on the machine and, for this purpose, the slide with table is rotated by 5 to 6°. The disks are made of a single piece of wood without knots or any other flaws. Disks made of an 87 % lead, 4 % tin and 9 % antimony alloy are more wear-resistant, and in addition give a better-quality polish.

Technical data, S-5 machine

Polishing rate, m/sec	4—7
Maximum pinion diameter, mm	30
Maximum module, mm	1
Polishing-disk diameter, mm	70--150
Polishing-disk spindle speed, rpm	750
Number of strokes of part slide per minute	113
Maximum spindle travel, mm	22

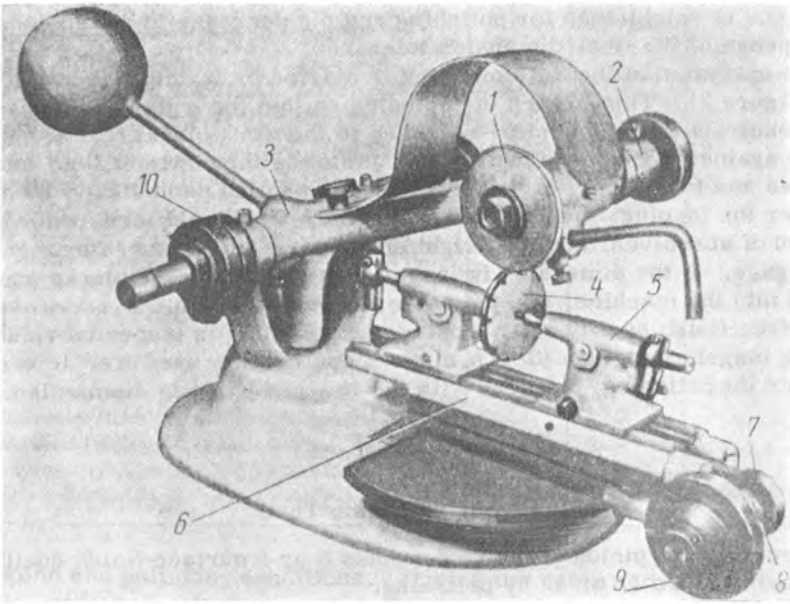

FIGURE 6. S-5 pinion-tooth polishing machine

In polishing, metal is removed more quickly from the tip of the tooth face than from the base of the tooth space, the reason being that the tip of the polishing-disk thread blunts rapidly. In order to avoid distortion of the tooth shape, the allowance for polishing is only 2 to 3 μ per side and the surface quality required after milling is accordingly very high so that only microroughness of 0.25 to 1.6 μ height need be removed by polishing.

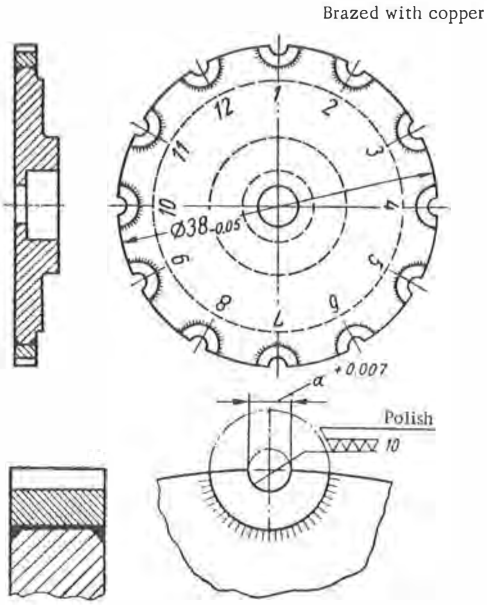

FIGURE 7. Steady-rest of the S-5 machine

The allowance for polishing is usually fixed at 0.005 mm per side, or 0.01–0.02 mm on a diameter. The polishing time is a function of the number of teeth, the module and the allowance, and is calculated using the formula

$$T_p = C_m \cdot M^{0.42} \cdot z^{0.7} \cdot \delta_s^{0.5}\text{*},$$

where C_m = a parameter depending on the surface finish, is taken between 0.12 and 0.20;
M = module, mm;
z = number of teeth;
δ_s = allowance for the tooth thickness.

The polishing time can also be determined from tables of standards (see Appendix 7). Thus, for $C_m = 0.2$, $M = 0.2$, and $z = 8$, $\delta_s = 0.01$ mm, $T_p =$ $= 0.044$ min.

External diameter, thickness and tooth profile are inspected after polishing by the same methods and using the same means as were used for inspection after milling. Surface finish is inspected visually using a magnifying glass (5×) or a microscope (16×).

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* Orgmashpribor Institute standards, 1954.

Polishing Journals and Shoulders

The cylindrical surface and shoulder of journals are polished simultaneously to surface-finish class 12 or 13 on the S-8a machine (Figure 8).

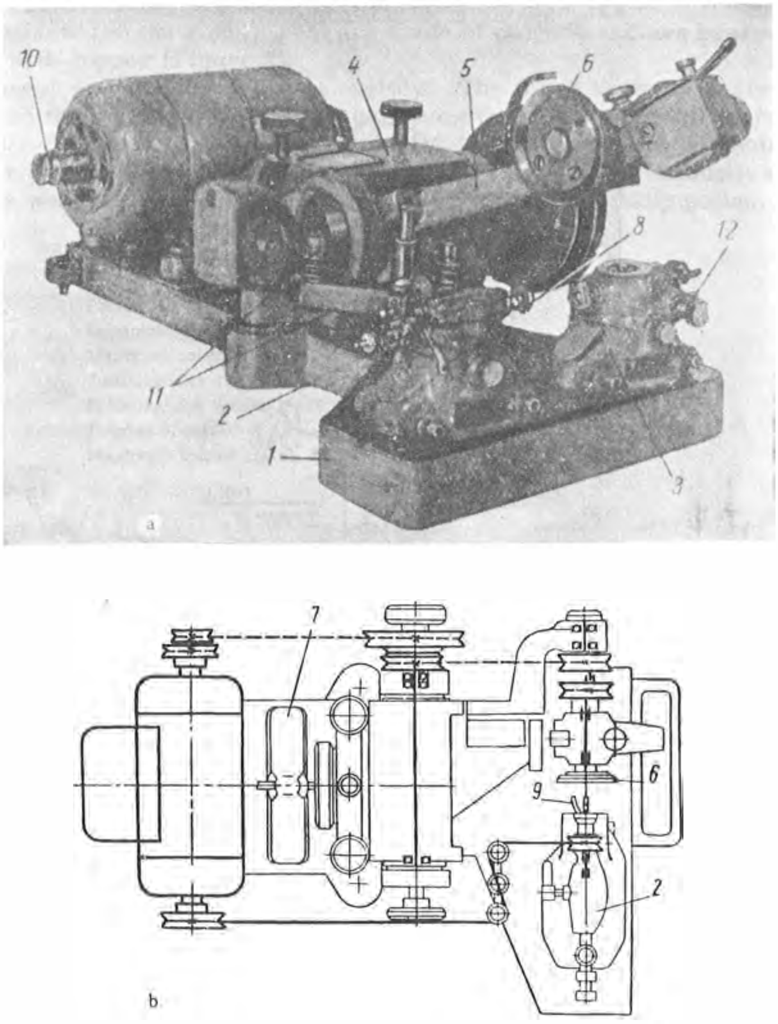


FIGURE 8. S-8a polishing machine for polishing journals and shoulders

The headstock (2), the steady-rest support (3), and the slide (4), with the rocker arm (5), are mounted on the bed (1) (Figure 8, a). The spindle with the polishing wheel (6) is fastened on the right end of the rocker arm, while its left end carries the counterweight (7) (Figure 8, b). The slide can be moved together with the rocker arm and wheel in the axial and radial directions during machine adjustment and the work headstock can also be moved axially during machine adjustment. The headstock holds the part against the stationary center (8) (Figure 8, a). The part is rotated by pulley (10), through idlers (11), and the driver (9) (Figure 8, b). Another driver is fixed to the part. When large pinions are polished, the driver is set directly between the teeth. A special, detachable headstock serves for holding the parts with the aid of a collet.

The rocker arm can be inclined to a maximum angle of 10° in the horizontal plane in order to polish the conical surfaces of shafts. The work and wheel spindles are driven by the electric motor.

A stop (12) restricts the descent of the polishing disk.

The steady-rest, which supports the journal to be polished, is made of hard alloy and is of a design similar to that of the steady-rest used for polishing pinion teeth (see Figure 7). When one bearing groove wears, the steady-rest is rotated and the next bearing groove located under the journal. The number of bearing grooves varies from 4 to 12, depending on the dimensions of the steady-rest and the bearings themselves.

The bearings grooves are cut and finished by means of diamond wheels or saws.

Technical data, S-8a machine

Diameter of the journals to be polished, mm	0.05—3
Maximum journal length, mm	8
Maximum length of the parts to be machined, mm . .	50
Speed of polishing wheel, rpm	860 or 1150
Speed of driver washer, rpm	3500
Polishing-wheel diameter, mm	36—75
Angle of rotation of the carriage, degrees	10
Electric motor	0.125 kw, 1.400 rpm

Carbide polishing wheels. Journals and shoulders are polished by a carbide wheel, lubricated in operation with mineral oil.

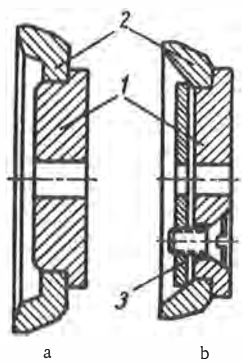


FIGURE 9. Carbide wheel

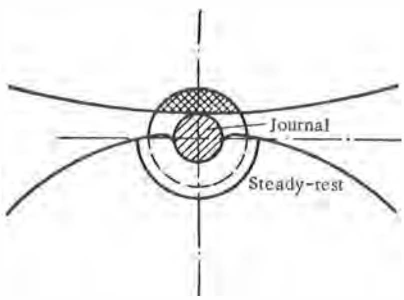
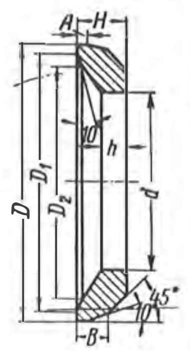


FIGURE 10. Contact between the polishing wheel and the part

The carbide wheel consists of a base washer (1) and a carbide ring (2) (Figure 9), which is either brazed to the washer (Figure 9, a) or screwed to it with the aid of plate (3) (Figure 9, b). The amount of carbide required for such rings is smaller than the amount required for a solid wheel. A composite wheel is also easier to balance, which is very important when small journals are polished, as a poorly balanced wheel can throw the journal out of the steady-rest. In all carbide rings the cylindrical working width A is larger than the working-face width, since the shoulder is usually several times shorter than the journal. The shape and dimensions of carbide rings are given in Table 4. The carbide alloys used are VK6, VK8 and VK10, all characterized by high wear resistance.

TABLE 4

Dimensions of carbide polishing rings



No.	D	D_1	D_2	d	H	h	B	A
1	36	34	34	34	6	3	6	1.5
2	51	49	49	34	7	3.5	4	2
3	65	63	57	42	11	5.5	6	2.5
4	75	73	67	42	11	5.5	6	2.5

Small grooves, inclined at 10 to 20° relative to the wheel axis and forming teeth of more or less regular shape are traced on the cylindrical and face ring surfaces. These teeth scrape the machined surface during operation.

The grooves on the face surface are finer than those on the cylindrical surface, as the metal-removal rate for the shoulder is considerably higher than that for the cylindrical surface. This is due to the fact that the cylindrical surface of the ring contacts the cylindrical surface of the journal along a narrow area, while the face surface of the ring and the journal shoulder contact along the hatched area (Figure 10). The polishing allowance for the shoulder is not much larger than that for the cylindrical surface and therefore, in order to finish the polishing of both surfaces at the same time, the face teeth are made by a finer diamond powder so that their cutting capacity is reduced.

Wheels having coarse, medium, or fine cut are used, depending on the surface-finish quality required. The relationship between the type of cut and the surface-finish quality is given in Table 5.

The part to be polished is fastened by one of its ends in the S-8a-machine headstock, while its other end is supported on the steady-rest (Figure 11). The polishing wheel is placed on the journal before the machine is started. The wheel and the work then begin to rotate; either in the same direction or in opposite directions. The wheel revolves at 860 or 1150 rpm, giving a peripheral speed of 200 or 270 m/min for a 75 mm diameter wheel.

The work spindle revolves at 3500 rpm, and the peripheral speed of the pinion journals is therefore between 2 and 6 m/min, which is much smaller than that of the wheel. The reversal of the sense of rotation of the work spindle therefore only slightly influences the resultant polishing speed.

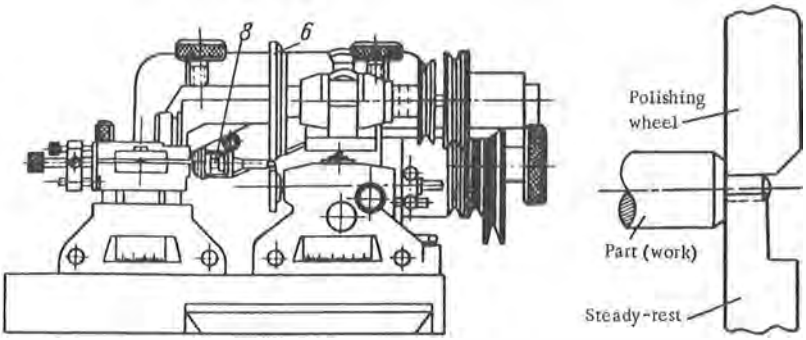


FIGURE 11. Position of the work in the S-8a machine

The basic production-rate index for the machine is the rate of metal removal (per minute), which depends on the diameter and the length of the polished surface, and on the magnitude of the allowance.

The larger the diameter and the longer the polished surface, the larger the surface of contact between the carbide ring and the work, and the higher the rate of metal removal. The rate of metal removal is calculated using the formula

$$W = C_W \cdot D^x \cdot l^y \cdot h^z \text{ mm}^3/\text{min}^*,$$

where D = diameter;
l = length of the polished surface;
h = diameter allowance;

The values of the factor C_W and the exponents x, y, z are given in Table 6.

The polishing (basic) time can be calculated using the formula

$$T_p = C_T \cdot D^a \cdot l^b \cdot h^c \text{ min}^*,$$

where D, l, h have the same meaning as in the previous formula, while the exponents a, b, and c are given in Table 6.

The polishing time can also be taken from the standards. A table of the polishing time for journals with 0.01 mm allowance and class ▽▽▽▽ 12 surface finish is given in Appendix 8. The spherical face of the balance staff journal is polished on the S-133 machine (Figure 12) after the cylindrical surface has been polished.

The balance staff is held in the headstock and on the steady-rest exactly as in the machine considered above. The polishing is performed by a carbide

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* Orgmashpribor Institute standards, 1954.

pivot, having on its lower working surface teeth similar to those on the wheel of the S-8a machine. The teeth on the front part are rough, while those on the rear part are fine.

TABLE 5

Polishing-wheel cut as a function of the surface finish required

Surface-finish quality class after polishing	Polishing allowance (on the diameter), mm	Wheel cut	Diamond grain size according to GOST 3647-47	
			for cutting cylindrical surface of wheel	for cutting face of wheel
10	0.02—0.05	Coarse	46	120
11	0.01—0.02	Medium	60	180
12—13	0.005—0.015	Fine	90	220

The balance staff revolves at a speed between 2140 and 4235 rpm and a reciprocating motion is all the while imparted to the polishing pivot by the machine link motion (Figure 13). The travel is 20 mm. The number of strokes per minute is 130, 188, or 258. The working plane of the pivot is in a horizontal position at the beginning of the travel, and in a vertical position at its end and the polishing pivot thus rotates through 90° from the beginning to the end of its travel in polishing the spherical face of the staff. The cycle duration is 3.5–5 sec.

TABLE 6

Factors and exponents for the determination of the rate of metal removal and the polishing (basic) time

Length of the surface to be polished	Rate of metal removal, mm^3/min				Polishing time, min			
	C_W	x	y	z	C_T	a	b	c
$l < 0.7$	7.5	0.65	1	0.5	0.20	0.35	0.4	0.5
$l > 0.7$	6	0.65	0.4	0.5	0.25	0.35	0.6	0.5

The electric motor (1) of the S-133 machine (Figure 13) drives the countershafts I and II through the right and left-hand pulleys and belt transmissions. Countershaft I drives the work spindle through pulleys (7) and (8). The link motion (5) is driven through the gear pair (2–3) and the polishing pivot (6) is connected to the link motion. Countershaft II drives the camshaft III through a worm and wheel. The camshaft carries the bell cam (4), which controls the feed of the carriage (11) by means of the rod (10). The carriage moves under the rough and the fine teeth of the polishing pivot alternately during one camshaft revolution.

Cam (9) switches off the machine after one camshaft revolution. After polishing, the balance-staff journal is buffed by means of a paste made of 75 parts diamantine and 25 parts beeswax. The surface finish achieved is of class 13.

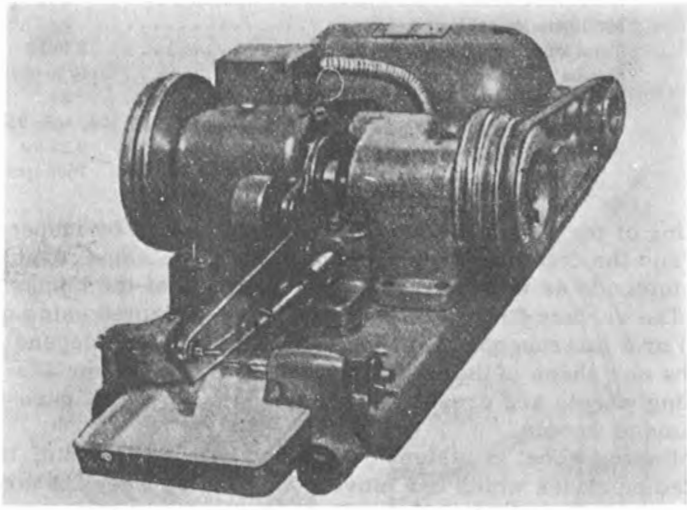


FIGURE 12. S-133 journal-rounding machine

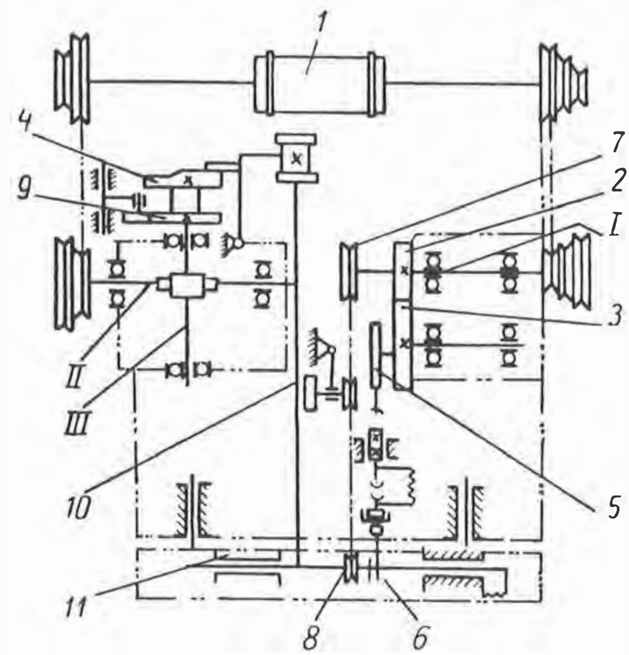


FIGURE 13. Kinematic diagram of the S-133 machine

Technical data, S-133 machine

Maximum diameter of the journal to be polished, mm	0.2
Maximum diameter of the journal to be polished, mm	0.05
Maximum journal length, mm	0.40
Total length of the part, mm	2 to 10
Spindle speed, rpm	2140 to 4285
Travel of polishing pivot, mm	20
Number of complete pivot strokes	130, 188, 258
Electric motor	0.25 kw 1500 rpm

Polishing of the journals and shoulders is followed by inspection of the diameter and the distance between shoulders by the same means and using the same methods as were used for the inspection of the blanks (see Chapter IV). The surface-finish quality is visually inspected using a magnifying glass (5×) or a microscope of magnification 16× to 70×, depending on the dimensions and shape of the surface inspected and on the surface-finish class.

Polishing wheels are dressed on the S-196 machine (Figure 14) by means of two diamond wheels.

The polishing wheel is fastened, together with the spindle, in the support (3) mounted on slides which can move the polishing wheel in three directions for adjustment. Two diamond wheels dress the two working surfaces of the polishing wheel consecutively in the same chucking.

The kinematic diagram of the machine is given in Figure 15. The electric motor, by means of round belts, drives the spindles for the diamond wheels (1) and (2) and for the polishing wheel being dressed. The slide can rotate through a maximum angle of 110° in order that the polishing wheel be dressed on the face and cylindrical surfaces at various angles.

The spindles of the diamond wheels can also move axially.

Technical data, S-196 machine

Polishing-wheel diameter, mm	30—120
Wheel width, mm	Up to 10
Diamond-wheel diameter, mm	75
Number of diamond wheels	2
Diamond-wheel speed, rpm	6000
Polishing-wheel spindle speed, rpm	900
Angle of rotation of the slide, degrees	110
Electric motor	0.35 kw 3000 rpm

Diamond wheels are widely used in watch production for dressing, grinding and finish-grinding of carbide tools, polishing wheels, punches, dies, templates, gages, etc.

The range of use of diamond wheels is given in Table 7.

The diamond wheel is made of two or three parts: body, base, and diamond layer (see Table 7, ASh-1a).

The bodies are made of aluminum or steel. Bakelite molding powder and cermet alloys are used for the base and for bonding the diamond grains. The diamond grains, of grain size strictly specified, are distributed homogeneously in the matrix (see Table 7).

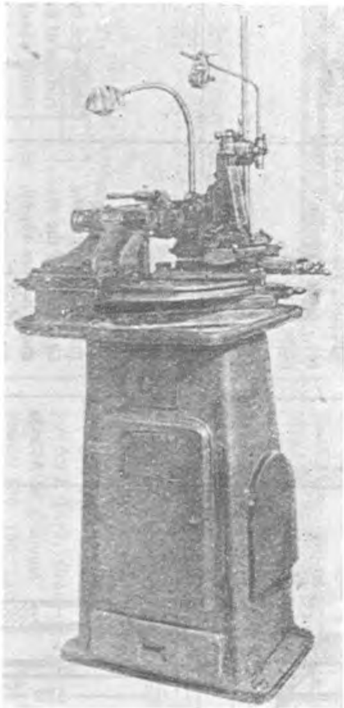


FIGURE 14. S-196 carbide wheel dressing machine

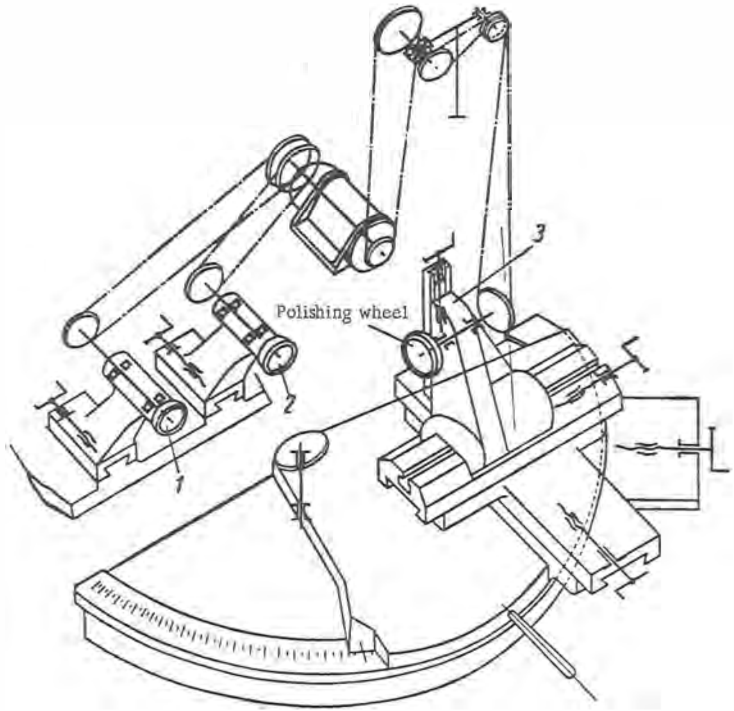


FIGURE 15. Kinematic diagram of the S-196 machine

TABLE 7

Range of use of diamond wheels

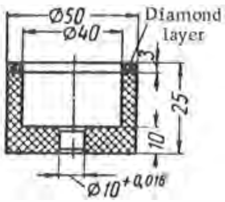
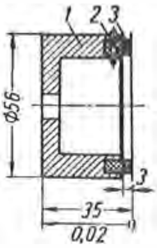
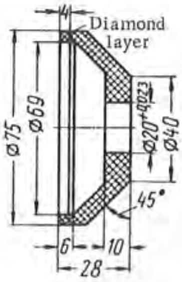
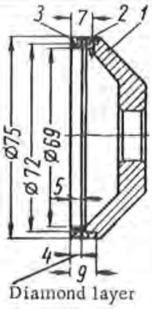
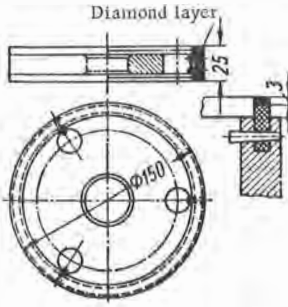
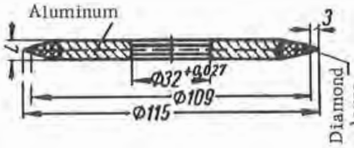
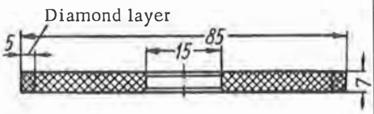
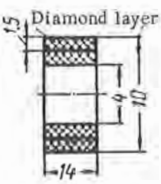
Drawings	Index	Description	Application
	ASh-1	Body and base—molding power K-18-2 GOST 5689-51. Diamond grain size 180, 320, M20, M14, M7. Concentration 50%, 40%.	Face cutting of carbide polishing wheels, finish grinding of punches, gages, etc.
	ASh-1a	Body—aluminum, base material—compound. Grain size of the diamond powder 46, 60, 90, 120. Concentration 100% and 50%.	Cutting the cylindrical surface of carbide polishing wheels. Roughing of carbide tools.
	ASh-3	Body and base—molding powder K-18-2 GOST 5689-51. Grain size of the diamond powder 180, 220, 280, 320, M20, M14, M7. Concentration 50%, 40%.	Face cutting of carbide polishing wheels, finish grinding of punches, gages, etc.
	ASh-3a	Body— aluminum, base material—compound. Grain size of the diamond powder 46, 60, 90, 120. Concentration 50%, 40%.	Cutting the cylindrical surface of carbide polishing wheels. Roughing of carbide tools.

TABLE 7 (cont'd)

Drawings	Index	Description	Application
	ASh-4 and ASh-4a	Body–aluminum, base material–molding powder K-18-2 for ASh-4, compound for ASh-4a. Grain size of the diamond powder 280, 320, M20, M14, M7 for ASh-4, 46, 90, 120 for ASh-4a. Concentration 100%, 50%.	Preliminary and final grinding of right-hand and left-hand tools with carbide bits, finish grinding of gages.
	ASh-5	Body – aluminum, base material – molding-powder K-18-2. Grain size of the diamond powder 280, 320, M20, M14, M7. Concentration: 100%.	Finish grinding of contour templates and contour tools.
	ASh-6	Body and base – molding powder K-18-2. Grain size of the diamond powder 280, 320, M20, M14, M7. Concentration 50%, 40%.	Finish grinding of center punches and and measuring standards.
	ASh-7	Body and base – molding powder K-18-2. Grain size of the diamond powder 120, 180, 220, 280, 320. Concentration 100%, 50%.	Finish grinding of the holes in carbide tools, dies, bushings, etc.

The bakelite bond is suitable for diamond powder of any grain size, beginning with number 46 and ending with number M-3.5. The cermet bond is suitable for diamond powder of grain size number 120 maximum; it rapidly loses its abrasive properties with a grain size above 150, due to loading. The metal chips which cause the loading are removed by etching. This phenomenon is not observed in bakelite-bonded wheels but their life is somewhat shorter than that of the cermet wheels.

Bakelite-bonded diamond wheels are manufactured by the method of hot molding. A mixture of bakelite and diamond grains is first poured into the press mold, and pure bakelite powder is then poured over it.

Cermet-bond diamond wheels are manufactured in the following manner. Cermet powder is poured into the press mold, leveled and premolded. A mixture of cermet powder and diamond grains is next poured and the whole is now pressed. To prevent burning-down of the diamond, a layer of graphite is poured into the press mold above the diamond layer. The pressed ring is baked in an oven at 800 to 820° for 20 to 25 min.

The ring thus obtained is fixed on a body, and fastening of the ring by pins and drilling (see Table 7 ASh–1a and ASh-3a) is performed in place.

Low-grade diamond, called "bort", is used in diamond wheels. Bort is extracted in the form of chips with blunt edges, and is crushed in porcelain or metal mortars into fine parts in order to obtain sharp-edged grains and to make the diamonds abrasive. The grains are subsequently classified and separated into grinding and polishing powders.

TABLE 8

Surface quality obtained as a function of the diamond grain size

Diamond grain size, according to GOST 3647-47	Grain size, μ	Surface-finish class, GOST 2789-51	Application
46	420–355	7	Rough grinding. Cutting the cylindrical surfaces of carbide polishing wheels.
90	180–150	8	Grinding. Cutting the cylindrical surfaces of carbide polishing wheels and rough grinding of carbide tools.
120	125–105	9	Grinding. Cutting the face of carbide polishing wheels and preliminary grinding of cutters.
180 220	85–63 75–53	10 10	Fine grinding. Cutting the face of carbide wheels and finish-grinding screw machine tools.
280 320	53–28 42–20	11 12	Lapping. Finish-grinding of screw machine tools, templates, gages.
Flours			
M–28 M–20	28–20 20–14	12	Polishing. Finish-grinding of contoured tools, templates, gages.
M–14 M–7	14–10 7–5	13	Fine polishing.
M–3.5	3.5–1.5	14	Finish-lapping of measuring standards.

The diamond concentration of the wheels varies and depends on the character of the work to be performed by them (concentration is the amount of diamonds, in carats, per 1 cm^3 of bond calculated as a percentage). The concentration is taken as 100% if there are 4.6 carats of diamond (1 carat = = 0.2 g) per cm^3 of bond of specific weight 1.25 g/cm^3. The concentrations used in diamond wheels are 100, 50, 40, and 25%. The lower-concentration wheels are used with low speeds and low feed rates. Higher concentrations are necessary when the part form (profile) has to be preserved.

Diamond is, as is well known, the hardest substance on earth. Its hardness is 10,060 units (in kg/mm^2) on the hardness scale for minerals proposed by Prof. M. M. Khrushchev, while the mineral occupying the second place – corundum – has a hardness of only 2060 units. Diamond surpasses by far all other abrasives in cutting speed, accuracy, and surface quality obtained. The abrasive capacity of one carat of diamond in sharpening a carbide tool is equivalent to that of 200 g of boron carbide. The chemical composition of diamond is pure crystalline carbon of specific weight 3.5.

The surface quality obtained is given in Table 8 as a function of the diamond grain size.

The wheels must be well balanced and water-cooled. The run-out tolerances on the working surfaces are indicated in the diamond-wheel drawings. Machines using diamond wheels must be free of vibrations.

Bakelite-bonded wheels are dressed by a pumice lump or a cutter in a lathe. Cermet-bonded wheels are dressed by corundum or carborundum disks with water.

The working speeds for diamond wheels are between 12 and 20 m/sec, and the feeds are 0.001 to 0.01 mm. Boron-carbide paste is used as a diamond substitute for tool sharpening. The use of boron-carbide abrasive in bonded wheels is made difficult by the fact that it is held poorly in a bakelite bond, while in a cermet bond it is rapidly oxidized during baking and is covered by an oxide film (at 500°) which reduces its abrasive capacity.

The introduction of carbide wheels has made it possible to dispense with the formerly widely used method of grinding and polishing with abrasive wheels, powders and pastes (in the nonbonded state).

Grinding and Polishing Keyless Wheels

The surface of the keyless wheels of pocket- and wristwatches undergo various decorative grinding and polishing finishing operations.

Differently finished keyless wheels are shown in Figure 16. Figure 16,a is a keyless wheel having a polished groove (2) on its face, and a central rim (1) finished with radial rays. The surface of the wheel teeth has a ground chamfer (3).

The surface of such wheels is finished in three operations: texturing the central rim (1), polishing the spherical groove (2), and polishing the chamfer (3).

Texturing consists in making small grooves on the outer surface of the wheels with the aid of emery paste or chromium-oxide paste.

The wheel planes are ground first. The ray-pattern texture is applied on the S-34 machine (Figure 17).

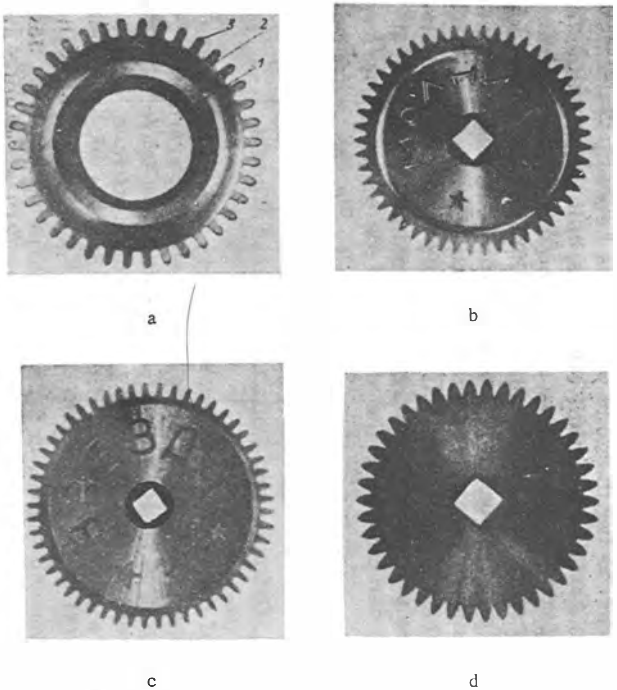


FIGURE 16. Finishes for keyless wheels

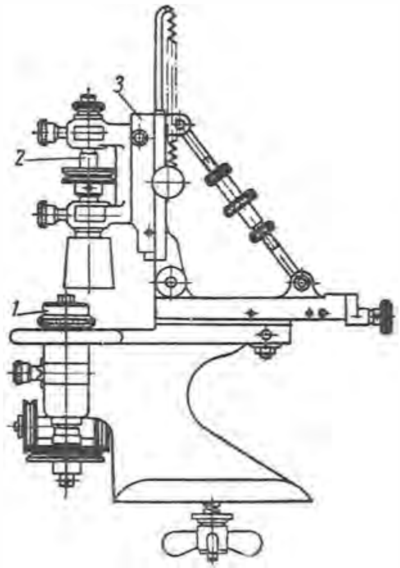


FIGURE 17. S-34 machine for texturing keyless wheels

The winding or keyless wheel is placed on the rotating table (1). A cup-shaped tool is fastened to the lower end of spindle (2). The head (3) of spindle (2) can be inclined in the vertical plane. The cup tool is made of D-1 duralumin or of an alloy containing 9% tin, 12% antimony, and the balance lead. Grade B emery paste is applied to the tool face and if a superior finish is required, this is replaced by grade A chromium oxide. The tool is so positioned relative to the part that its circumference passes through the part center. When the two spindles revolve simultaneously and the cup-tool face is in contact with the part face, a design is obtained on the part. Differently directed rays will be obtained depending on the ratio of the peripheral speeds of the cup tool and the part. The inclination of the tool relative to the part plane gives clearer designs.

No allowance is specified for texturing, and the part maintains the dimensions from the preceding operation. The layer removed is 5–7 μ thick.

Technical data, S-34 machine

Worktable speed, rpm	1300
Cup-tool speed, rpm	1800
Maximum diameter of the part chucked in the collet, mm	12
Cup-tool dimensions, mm:	
outer diameter	46
inner diameter	37
height	45
Angle of rotation of the horizontal slides	± 5°40'
Angle of inclination of the tool head	± 3°40'

The keyless-wheel flutes are lapped on a special machine using grade B emery paste applied along the circumference of a cast-iron or copper wheel. The paste used for polishing is grade B chromium-oxide paste applied along the circumference of a leather wheel.

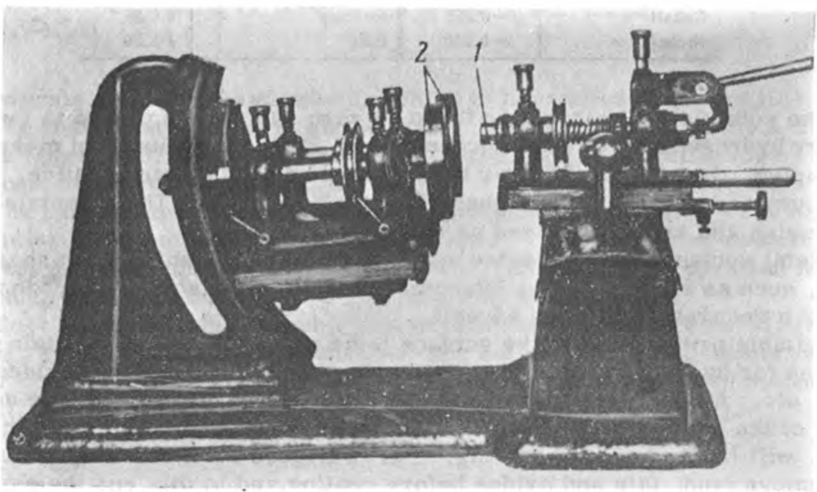


FIGURE 18. S-172 machine for grinding keyless-wheel chamfers

The chamfers are ground on the S-172 machine (Figure 18). The keyless wheel is chucked in the collet of the spindle (1) on the head. The abrasive wheels (2) face-grind the chamfers alternatively. The work spindle is fed manually.

Figure 16,b shows a wheel without chamfers, whose flute has very small width and depth.

Figure 16,c is a wheel without flute and with a peripheral chamfer only.

Figure 16,d shows a wheel without flute or chamfer. This wheel is subjected to texturing only.

The surface quality is inspected visually using a magnifying glass (5×).

PREPARING SURFACES FOR COATINGS

Atmospheric air always contains a certain amount of moisture, and this moisture together with the oxygen of the air attacks metals and destroys them slowly, the phenomenon being known as *corrosion*. Corrosion begins at the metal surface, marring its external appearance, gradually penetrates into the metal and lowers its mechanical strength. The resistance of a metal to corrosion is determined by the value of its electrode potential: the higher the potential, the higher the resistance to corrosion. The electrode potentials of some metals are given in Table 9.

TABLE 9

Electrode potentials of metals

Metal	Potential	Metal	Potential
Aluminum	−1.84	Tin	−0.14
Zinc	−0.76	Lead	−0.13
Chromium	−0.56	Hydrogen	0.000
Iron	−0.44	Copper	+ 0.34
Cadmium	−0.40	Silver	+ 0.80
Cobalt	−0.255	Mercury	+ 0.85
Nickel	−0.250	Gold	+ 1.50

The potential of hydrogen is taken as zero and metals placed in the table before hydrogen are called electronegative. Zinc, chromium and nickel are examples. Metals placed after hydrogen are called electropositive. Silver, mercury and gold have the highest positive potentials. These metals resist corrosion and are categorized as noble metals.

Metal surfaces are protected against corrosion by surface finishes (coatings, such as electroplating, chemical coating, varnishing), which in watches serve a decorative purpose as well.

Suitable preparation of the surface to be coated is one of the main preconditions for successful coating. The surface must be free from oxides, fats, oils, etc. A thin film of fat or oil is sufficient to prevent the close adherence of the coating to the surface. Surfaces contaminated by sand or dust, etc., will have an uneven coating. Part surfaces are accordingly cleaned to remove mud, fats and oxides before coating and to this end the parts are tumbled in barrels, ground polished, scratched, degreased, and pickled.

The processing method selected and the sequence of operations depend on the surface condition resulting from the preceding mechanical operations, on the metal, and on the type of finish to be applied.

Tumbling

Tumbling in revolving barrels is used for removing from the metal surface burrs, rust, oxides and contamination in general. The parts are loaded into the barrel in batches together with abrasives such as emery, broken glass, hardwood sawdust, quartz sand, gravel, etc. If a more thorough cleaning is required, leather scraps and soap solution are added. Barrels are round or polyhedral, and some designs permit them to be tilted to allow a more intense agitation. Tumbling is continued for several hours and as the parts rub against each other, their sharp angles are blunted, burrs are removed, and the surfaces are cleaned. The barrel revolves at speeds between 15 and 60 rpm.

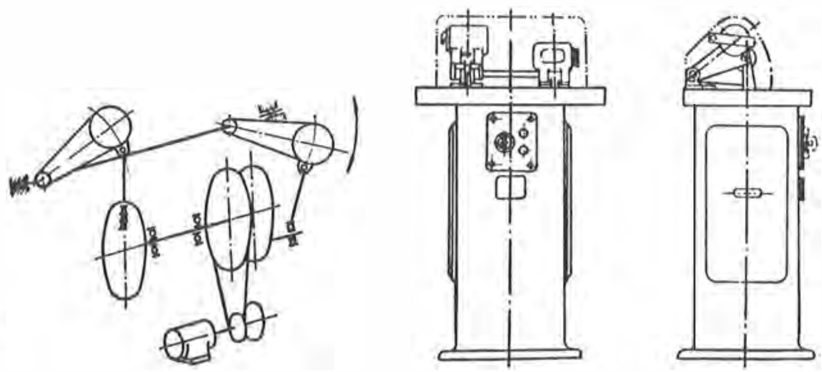


FIGURE 19. S-205 machine for tumbling small-size parts

Barrels are loaded and unloaded through hermetically sealed lids.

The fine parts of pocket- and wristwatches are tumbled in the S-205 machine (Figure 19), in which two double barrels are set oscillating by a crank mechanism placed in the machine base.

The barrels are removed from their housings for loading. The barrel diameter is 75 mm and their capacity 1 liter. The number of complete strokes per minute is between 355 and 500. The tumbling duration is between 10 and 30 minutes and is controlled by a time relay.

Most blanked parts are subjected to tumbling for burr removal, and many parts, such as the pocket-watch bow, are polished by this process, since their complex shape makes grinding and polishing by any other method difficult.

Polishing as a preparatory operation to electroplating is applied mainly to the nonferrous parts of watches: cases and dials. The parts are polished on S-24 machines by felt wheels, 40–50 mm thick and of 400 mm maximum diameter (Figure 20). Abrasive powder is glued to the surface of the wheels.

The last mechanical operation before plating is polishing and this operation gives the parts the gloss necessary for protective-decorative finishes. S-42A machines are used with textile fabric wheels and the abrasive is chromium-oxide paste. The peripheral wheel speed for preliminary rough polishing averages 25 to 35 m/sec and the final-polishing speeds are between 30 and 40 m/sec.

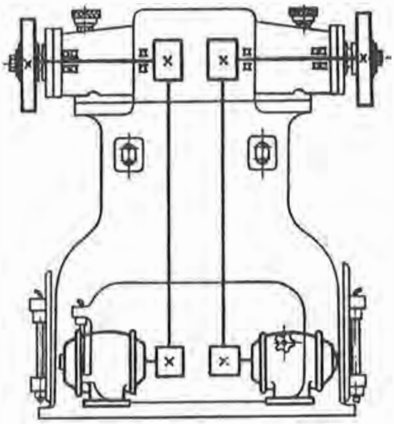


FIGURE 20. S-42A machine for rough- and finish-polishing nonferrous parts

Emery of various grain sizes, and chromium-oxide pastes are used for polishing (see Table 2).

Abrasive materials are classified into three groups according to grain size (GOST 3238-46 and 3647-47), grains, powders, and flours. Dimensions are given in Table 10.

Coarse grains are glued to wheels by joiner's glue. Fine grains are bonded using stearin, paraffin, oleic acid, beeswax, etc.

After finishing (coating) S-42A machines are used with steel, brass, bristle or horse hair and vegetable-fiber brushes to give the coatings a uniform hue or metallic gloss and to remove any remaining dirt or oxides. This operation is called scratch-brushing.

TABLE 10

Grains				Powders		Flours	
Grain size, No.	Grain size, μ	Grain size, No.	Grain size, μ	Grain size, No.	Grain size, μ	Grain size, No.	Grain size, μ
10	2300—2000	36	600—500	100	150—125	M-28	28—20
12	2000—1700	46	420—355	120	125—105	M-20	20—14
14	1700—1400	54	355—300	150	105—85	M-14	14—10
16	1400—1200	60	300—250	180	85—75	M-10	10—7
20	1200—1000	70	250—210	220	75—63	M-7	7—5
24	850—700	80	210—180	240	63—53	M-5	5—3.5
30	700—600	90	180—150	280	53—42	M-3.5	3.5—1.5
				320	42—28		

The brush wires must be elastic, and are accordingly given a corrugated shape. The finer the wire, the better the surface finish obtained. The brush wires are usually of 0.08 to 0.10 mm diameter and the liquid used during scratch-brushing can be soapy water, French chalk, chalk, etc.

Dial surfaces are subjected to scratch-brushing before and after the silver-plating in order to give them an even shade (instead of sand-blast processing).

Chemical Degreasing and Pickling

Parts sent for electroplating are usually contaminated by fats and the first operation is therefore chemical or electrochemical degreasing. Alkaline solutions, alkaline salts, and special organic solvents are used in chemical degreasing.

The fats which contaminate parts are classified as saponifiable and nonsaponifiable fats. Vegetable and animal fats, such as linseed oil, colza oil, stearin, tallow, olein, etc., belong to the first group. These fats break up under the action of alkaline solutions and produce soaps which are soluble in water. Mineral fats, such as mineral oils, vaseline, paraffin, grease, etc., are in the second category and they do not break up under the action of alkaline solutions, but form emulsions (mixtures of liquids insoluble in one another).

Upon emulsification, the alkaline solutions break the films of fat on the metal surface and form fine fat drops. The drops remain in the liquid in a suspended state and the soap and emulsion obtained as a result of the chemical degreasing are easily removed from the surface by cold or hot water. The rate of degreasing is increased by heating the bath to 90° and agitating it periodically. Water glass, soap and other emulsifiers are added to the bath in order to speed up the process. Both saponifiable and nonsaponifiable fats are removed by solvents such as kerosene, gasoline, toluene, carbon tetrachloride, dichlorethane, and trichlorethylene. The three last-mentioned solvents differ from the first three in that they are not inflammable allowing the degreasing to be conducted in conjunction with heating. Their shortcoming is their toxicity, which makes good ventilation mandatory when working with them.

Alkaline solutions of the following composition are used at a temperature of 70 to 90°C for the chemical degreasing of steel and brass parts with unpolished surfaces: 20 to 30 g/l caustic soda, 25 to 30 g/l sodium phosphate or carbonate and 3 to 10 g/l water glass or soap. Degreasing takes 20 to 30 min and is followed by rinsing in very hot water and drying. The degreasing quality is determined by wetting the surface with water. The wetted part is positioned vertically, and its water film is observed. No discontinuities will be observed in the film if the degreasing is satisfactory. The water film will break down in those places were fat or oil spots remain.

The next operation, after degreasing, is pickling which consists in the removal of oxides from the metal surface by immersing the part in acid, alkaline or acid-salt solutions. Pickling can be chemical or electrochemical.

Ferrous metals are chemically pickled using sulfuric, hydrochloric, phosphoric or nitric acid or mixtures of them. The process is more rapid in hydrochloric acid than in sulfuric acids and the pickling can be speeded up by heating the bath to 30–40°C. Phosphoric- or nitric-acid pickling forms insoluble iron phosphates on the surface which aid in the satisfactory adherence of paints etc. Phosphoric-acid pickling is slower than sulfuric-or hydrochloric-acid pickling. Nitric acid is used relatively rarely for pickling ferrous metals, and is used in a mixture with hydrochloric acid.

Chromium steels resist sulfuric acid and dissolve in pure hydrochloric acid or in hydrochloric acid mixed with other acids.

A mixture of nitric, hydrochloric and sulfuric acids in various proportions is used for pickling brass and other nonferrous metals and alloys. Before the protective finish is applied, the parts are pickled in a solution of nitric and sulfuric acids (in equal proportions by volume) with a small amount of common salt (20 g per liter of mixture). This operation imparts a glossy surface to nonferrous metals, and is accordingly sometimes considered a final operation.

Normally, however, the parts are finally pickled for several seconds in a bath of the following composition after the preliminary pickling:

HNO_3 (specific weight 1.38)	1 liter
H_2SO_4 (specific weight 1.84)	1 "
HCl (specific weight 1.17)	2 cm^3
Dutch soot	10 g
Solution temperature	50—60°C

The pickled parts are rinsed in hot and cold water, or in cold water only.

Electrochemical Degreasing and Pickling

Degreasing with electric current in an alkaline solution is more effective than ordinary chemical degreasing. The electrolytes used are caustic soda, potassium carbonate, sodium carbonate, or sodium phosphate, etc. Emulsifiers such as soap or water glass are sometimes used. The process of electrochemical degreasing consists in emulsifying the fats and oils with the aid of the hydrogen bubbles liberated at the cathode. The gas bubbles penetrate below the film of fat and break it up, and fine fat droplets are formed as a result.

Degreasing proceeds more quickly when the electrolyte is heated to 60° or 70°C and agitated. Steel parts such as springs, plates, etc. are liable to be saturated with hydrogen which, liberated in great quantity at the cathode, penetrates the metal and makes it brittle. The adherence of electric platings to hydrogen-saturated metal is poor. Parts made of high-carbon steel are accordingly degreased by anodic degreasing.

Alkaline solutions and electrochemical degreasing conditions

For steel and cast iron (cathodic and anodic degreasing)

Caustic soda	10—20 g/l
Sodium phosphate or carbonate	25—50 g/l
Water glass	3—5 g/l
Solution temperature, °C	70—80
Current density, amp/dm^2	3—10
Duration of degreasing, min:	
cathodic	2—3
anodic after cathodic	1—2

For brass (cathodic degreasing)

Sodium phosphate	25–30 g/l
Sodium carbonate	25–30 g/l
Soap or dextrin (optional)	3–5 g/l
Solution temperature, °C	50–70
Current density, amp/dm^2	3–10
Duration of degreasing, min	1–2

For nickel (cathodic degreasing only)

Caustic soda	10–20 g/l
Sodium carbonate	15–30 g/l
Solution temperature, °C	70–80
Current density, amp/dm^2	3–10
Duration of degreasing, min	Up to 3

Electrochemical pickling is performed both at the cathode and at the anode. The electrolyte used in anodic pickling is an acid solution or a solution of the salts of the corresponding metal. The part to be pickled serves as anode, and the cathode is made of lead, copper, or iron, etc. The current density is 5–10 amp/dm^2 and the voltage is between 3 and 10 v.

The electrolyte used in cathodic pickling is a mixture of sulfuric and hydrochloric acids. The anode is made of lead, a lead-antimony alloy (6–10% Sb), or silicon cast iron (20–24% Si). The part to be pickled constitutes the cathode. The current density is roughly the same as in anodic pickling.

Electrochemical pickling is speedier than chemical pickling and uses less acid. It is also less harmful than chemical pickling, as it uses weaker solutions.

After pickling, the parts are rinsed in hot and cold water.

Before electroplating, copper and copper-alloy parts are processed in a solution of hydrochloric acid (40 to 60 g/l) or of potassium cyanide (40 to 60 g/l). This variant of pickling removes the oxide film on the metal surface and exposes the metal structure for better adhesion of the coating. The solution is at room temperature and the parts are held in it for 20 to 30 sec, after which they are rinsed in cold running water.

ELECTROPLATING

Electroplating involves the electrodeposition of a metallic coating 0.0005--0.1 mm thick on a metallic part from an electrolyte. The electrolyte is an electroconductive solution of metallic salts and is connected in the d. c. circuit by means of conductors called electrodes. The electrode connected to the positive pole of the current source is called the *anode*, and that connected to the negative pole is the *cathode*.

The part to be plated is used as cathode in the electroplating process, while the anode is a plate consisting of the metal which is to be deposited (Figure 21). This type of anode dissolves with the deposition of metal on the cathode and its weight accordingly decreases, and necessitates periodic replacement. Insoluble anodes are used for certain types of plating: for example, lead anodes for chromium-plating.

The surface area of the anodes is at least equal to the cathode area and mostly up to 50% larger. Passage of electric current in the electrolyte causes a continuous change in its composition near the electrodes: metallic ions and hydrogen are concentrated near the cathode and nonmetallic ions and acid radicals are concentrated near the anode. This process is called electrolysis.

The amount of metal deposited on the cathode will always be less than the amount calculated theoretically, due to secondary phenomena such as hydrogen liberation, etc. The ratio between the actual and theoretical values of metal deposition is called the current efficiency.

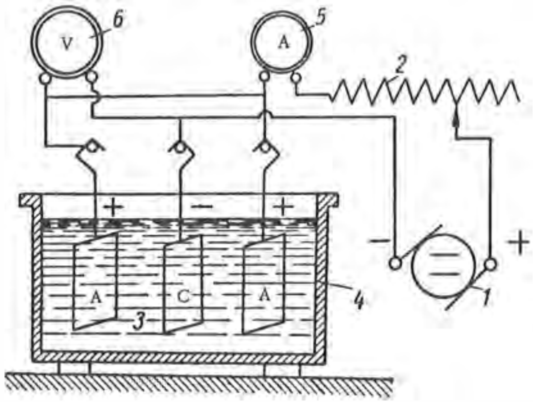


FIGURE 21. Layout of an electroplating installation:

1–d. c. generator; 2–rheostat; 3–electrolyte; 4–tank; 5–ammeter; 6–voltmeter; A–anodes; C–cathode.

The current efficiency is expressed in per cent. It is 94–99% for copper baths, 75–85% for zinc baths and 12–15% for chromium baths. Another parameter of electrolysis is the current density (the current per unit surface of the plated part), measured in amperes per square decimeter.

Electroplating processes in which the potential of the coating metal is more negative than that of the base metal (see Table 9), such as the electroplating of zinc on iron, are called anodic coating*.

Cathodic plating processes are those in which the coating metal has a more positive potential than the base metal, such as the plating of nickel or copper on iron.

Anodic coating gives better protection against corrosion than does cathodic coating since the coating metal has a more negative potential and it is therefore this metal which is consumed, while the base metal remains intact. Zinc-plated iron (anodic coating) will thus be more corrosion-resistant than tin-plated iron (cathodic coating).

Chromium-plated iron is an exception. Although the potential of chromium is more negative than that of iron, it is nevertheless the iron which is attacked by corrosion, through pores in the chromium coat. This is due to the property of chromium which causes it to passivate itself rapidly and so become as corrosion-resistant as the noble metals Anodic coatings

* The terms anodic and cathodic coating refer only to the relationship between the base metal and the coating metal, and not to the electroplating process itself.

do not have an attractive appearance. The only protection which cathodic coatings provide for the base metal is mechanical, they cover it and so protect it against moisture and chemical reagents. If the coating has pores, the base metal will be attacked even more rapidly than if it were bare. The greater the difference between the potentials of the coating and the base metal, the higher will be the rate of consumption of the metal of lower potential. A multiple-layer coating of dissimilar metals, such as copper - nickel - chromium is used to achieve a nonporous chromium coating.

The plated layer must strongly adhere to the base metal and should be inseparable from it by mechanical means. It must be continuous, with a minimum of pores, as thick as specified, as uniform as possible over the entire surface, and it must present sufficient resistance to mechanical wear.

Decorative coatings must, as a rule, be glossy either directly after being taken out of the bath or after polishing.

The desirable features in electroplated layers are a fine grain and a smooth, bright or glossy appearance.

The main factors determining plating quality are, in addition to the preparation of the part surfaces, electrolyte composition, agitation, temperature, current density, and acidity of the electrolyte. Electrolytes used here are acid or cyanide solutions:

Acid electrolytes are solutions of simple salts of sulfuric, hydrochloric and nitric acids: copper sulfate, nickel sulfate, nickel chloride, etc. These electrolytes give deposits of larger grain than do cyanide electrolytes.

Cyanide electrolytes are solutions of complex compounds of sodium cyanide or potassium cyanide with copper or other metals. Cyanide baths produce electrodeposits with a fine-grained structure that uniformly cover the surface. Potassium cyanide and sodium cyanide decompose in the electrolyte and liberate the very toxic prussic acid making an efficient ventilation system an absolute necessity. Cyanide electrolytes are more expensive than the acid types. To obtain fine-grained deposits in an acid bath, the concentration of salts and the current density are increased.

The acidity of the bath is sometimes adjusted by introducing in nickel baths the so-called buffer additives, such as boric and citric acids. Foreign salts and organic substances are sometimes introduced in small quantities in the electrolyte to obtain small grain size and bright coatings: cadmium chloride is used in zinc-plating, and sulfonaphthalic acid in nickel-plating. Bright coatings are more economical than mat coatings since the latter usually have to be polished, which entails additional expense and reduces the coating quality. Bright nickel is used in watches on the movement bridges, and for some steel parts.

High-quality coatings can be obtained only from an electrolyte which is free from any contamination (1 % nitric acid in a chromium bath prevents the deposition of metal), and electrolytes are therefore systematically filtrated. The electrolyte must be agitated during plating in order to equalize its concentration. The cathodic layer is continuously impoverished by the liberation of metal ions and agitation makes it possible to use a higher current density and thus to speed up the deposition process. The same effect can be achieved by raising the temperature which increases the ion movement in the solution and therefore the concentration of metal ions at the cathode. An excessive increase in the temperature can, however, lead to negative results as it increases the rate of decomposition of certain components of the solutions, especially in cyanide baths, and causes the formation of vapors. The temperature of electrolytes operating at high current density must not exceed 40 to 55°C and should be within the limits of 18 to 25° for low current densities.

The structure of the deposit also depends on the current density. Deposits produced with low current densities are porous and deposits produced with normal density are continuous, dense and fine-grained. Current density can, however, be increased only within certain limits and if this limit is exceeded the electrolyte near the cathode is rapidly impoverished and a low-quality coating results. This can be avoided by increasing the concentration of salts in the bath and by agitating the electrolyte. Increased current density generally accelerates the process of metal deposition. The current density varies within wide limits for different electrolytes: for gold-plating it is 0.1–0.3 amp/dm^2; and for chrome-plating it is 50 amp/dm^2 and more.

Porosity is one of the main shortcomings of electroplatings as the presence of pores favors corrosion. Porosity depends mainly on the layer thickness: the thicker the layer, the smaller the porosity. Porosity also depends on the preparation of the surface before plating and on the presence of gas (mainly hydrogen) bubbles at the surface. Multiple-layer plating is used to eliminate porosity. The thickness of the electroplated layer is of decisive importance in the protection of parts against corrosion and mechanical wear. The coating thickness is calculated using the formula

$$a = \frac{D_c \cdot C \cdot n \cdot t}{d \cdot 1000},$$

where a = coating thickness, mm

D_c = current density, amp/dm^2;

C = electrochemical equivalent, g/amp-hour (from handbooks);

n = current efficiency, %;

t = deposition time, hours;

d = specific weight of the deposited metal, g/cm^3.

This formula is used for determining the average coating thickness. The actual thickness at edges and projections will be greater than on flat surfaces and in recesses. This is due to the imperfect throwing power of the electrolytes. The throwing power of the bath is estimated from the difference in the coating thickness in a given suspended group of parts. The greater the electrolyte throwing power, the more uniform will the metal deposit on the surface be. Cyanide baths have better throwing power than have acid baths. Difficulties caused by a low throwing power are overcome by the use of additional cathodes, screens, shaped anodes, etc.

The deposit quality also depends on the electrolyte acidity. The acidity (or alkalinity) of electrolytes is characterized by the pH numbers (Table 11).

The pH number is determined by potentiometers or by indicators. Indicators change color in accordance with the concentration of hydrogen ions in the solution. The value of pH is always given when the electrolyte bath and conditions are specified, especially for nickel-plating and zinc-plating. The recommended pH number for nickel baths is 5 to 5.5.

Copper, nickel, chromium, zinc, silver, and gold coatings are widely used in watch production.

Copper-plating is used as an undercoating for nickel, chromium, or silver plating. The copper-coating thickness does not exceed 15 μ. The use of copper-plating for protective and decorative coatings is not advisable, as copper has a high electropositive potential and cannot protect iron against corrosion. In addition, copper is easily oxidized and tarnished in atmospheric air.

Electrolytes used for copper-plating are of the acid or the cyanide type.

TABLE 11

The pH numbers of various solutions

Reaction of solution	pH number
Strongly acid	1–3
Weakly acid	4–6
Neutral	7
Weakly alkaline	8–10
Strongly alkaline	11–14

The acid copper electrolytes include two components: 200 to 250 g/l of copper sulfate ($CuSO_4 \cdot 5H_2O$) and 50 to 60 g/l of sulfuric acid. The temperature is 18 to 25°C and the current density 1 to 3 amp/dm^2.

The acid electrolytes are stable in operation, less sensitive to contamination and suitable for high current densities (up to 20 to 30 amp/dm^2). The current efficiency is near 100%. Their shortcoming is their poor throwing power which leads to the formation of a coarse-grained and porous coating of uneven thickness and poor adherence.

Cyanide electrolytes are therefore generally used for the first layer (2–3 μ thick), which is then increased to 20 μ in an acid bath.

Cyanide copper electrolytes give a deposit of fine-grained structure, showing good adherence to the base metal. They have better throwing power and operate at lower current densities. Their shortcoming lies in their toxicity. Various copper cyanide electrolyte compositions exist. The following composition is widely used for copper-plating brass and steel parts:

Copper cyanide CuCN	12–18 g/l
Sodium cyanide NaCN, ...	4–6 g/l
Sodium hyposulfite $Na_2S_2O_3 \cdot 5H_2O$	1–2 g/l

The holding time is 1 to 2 min at 30 to 40°C. The current density is 0.5 to 0.8 amp/dm^2. Satisfactory results are obtained by periodically reversing the polarity of the plating current.

Nickel-plating is used both as an underlayer for chrome-plating and as an external protective-decorative coating. Its wide use is due to the physical properties of deposited nickel. Nickel like chromium readily becomes passivated and is therefore corrosion-resistant and preserves its gloss for a long time. It can be well polished, and it adheres well to the base metal. The deposit structure is very fine and is difficult to see even under high magnification. Nickel coatings are very hard and wear-resistant. Nickel coatings on iron are of the cathodic type and, if porous, will cause the base metal to corrode. Nickel coatings on brass and copper are 2 to 5 μ thick. Parts working in atmospheric air are subjected to a multiple-layer coating, whose total thickness is 5-10 μ.

Nickel electrolytes are very varied in composition. The following bath composition, used in several watch plants, can be recommended for decorative coating of brass:

Nickel sulfate ($NiSO_4 \cdot 7H_2O$) 200 to 300 g/l (contains 21.4% metallic nickel).

Common (table) salt (NaCl) 5 to 25 g/l. Added for the prevention of anode passivation.

Boric acid (H_3BO_3) 25 to 30 g/l. Added for sustaining the bath acidity within specified limits. The bath temperature is 20 to 40°C and the current density 1 to 3 amp/dm^2. The holding time is 12 to 20 min.

For bright-nickel-plating 2 to 4 g/l of disulfonaphthalic acid and 4 to 6 g/l of sodium or potassium fluoride are added to the solution. The common-salt content is reduced to between 5 and 15 g/l. A 1 to 2 μ thick bright-nickel coating is used for corrosion protection of steel watch parts such as the pawl and the regulator.

Black-nickel plating is used to obtain a glossy black field on dials. The dials are first degreased chemically, pickled twice, and then plated in an electrolyte of the following composition:

$NiSO_4(NH_4)_2SO_4 \cdot 6H_2O$ – 60 g/l; $ZnSO_4 \cdot 7H_2O$ – 7.5 g/l; NH_4CNS – 15 g/l.

The current density is 0.10 amp/dm^2, the electrolyte is used at room temperature, the holding time is 20 min, and the plated parts are rinsed in cool water.

Nickel baths are more sensitive to contamination than any other electrolyte. Iron, zinc, and copper are detrimental admixtures and pass to the cathode together with the nickel. This results in a darkened coating surface with point-corrosion marks and the plated layer is brittle and peels off easily.

Poor-quality nickel plating is often due to changes in the electrolyte acidity, and therefore in the current efficiency, which is linked with the liberation of gas. The pH number for nickel baths is usually between 4.5 and 6.

The deposits obtained from an electrolyte with low pH (relatively high acidity) have a finer structure and are harder and more brittle than are deposits obtained from low-acidity baths.

Nickel-base electrolytes must be agitated and filtered periodically.

Chromium plating is one of the main plating processes used in watch production. Chromium is a hard, brittle metal, with a silver-steel color which strongly resists mechanical wear and the action of organic acids, nitric acid, alkaline solutions, ammonia, and the solutions of many salts. It is dissolved in hydrochloric and sulfuric acid. Although the electrode potential of chromium is more negative than that of iron, it is easily passivated and so becomes cathodic relative to iron. A distinct advantage of chromimum over nickel and silver is that chromium retains its luster if exposed to air for a long time, even at temperatures of the order of 450 to 500°C. Another distinct advantage, this time over nickel and copper platings, is that no polishing is needed to achieve a mirror finish.

Porosity is the main shortcoming of chromium coatings. Decorative chromium plating is accordingly applied on copper and nickel undercoatings, which are buffed to a mirror finish before the chromium layer is applied.

The chromium layer is usually not more than 1 to 2 μ thick but may be as much as 4 to 6 μ in certain cases (wrist- and pocket-watch cases).

Hard-chromium plating, the object of which is increased service life for dies, gages, and other tools rather than decoration, is another type of chromium plating. The life of chromium-plated tools is increased 5 to 8 times compared with unplated tools. No copper or nickel undercoating is used for hard-chromium coatings and the layer is usually 5 to 10 μ thick, although in some cases a thickness of 80 μ is obtained.

Chromium-plating considerably differs from other electroplating processes, both with respect to the electrolyte composition and to the working conditions. The electrolytes basically consist of chromic acid (chromic anhydride) and sulfuric acid. The minimum current density is 5 to 7 amp/dm^2 and the current efficiency 12 – 15%. Chromium precipitates with considerable liberation of hydrogen, which carries along droplets of the toxic chromic acid. Special exhausters mounted on the bath are used to draw off chromic-acid vapors.

A shortcoming of chromium-plating is the poor throwing power of the electrolyte. Additional anodes and screens are accordingly used for chromium-plating contoured parts. In addition, the chromium-plating bath works with insoluble lead anodes, so that the electrolyte composition must be adjusted more often. The electrochemical equivalent of chromium is very low (0.323 g/amp. hr), making it necessary to use higher current densities and longer holding times than for other plating processes. The high current densities necessitate a reliable contact between the part and its suspension and the cathode rod.

The following electrolyte compositions and working conditions are used for decorative chromium-plating of wrist- and pocket-watch cases:

Chromic acid (CrO_3)	350–400 g/l
Sulfuric acid (H_2SO_4)	3–4 g/l
Current density	4–5 amp/dm^2
Temperature	40–45°C
Holding time	40–50 min

Z i n c - p l a t i n g is applied to several internal parts of alarm clocks and wall clocks. Zinc protects iron against corrosion because it has a more negative electrode potential than iron. Zinc coatings dissolve in all acids and alkalies, and are rapidly destroyed by moisture. The zinc layer must accordingly be 5 to 12 μ thick in order to ensure the protection of the base metal against corrosion. Three types of electrolytes are used for zinc-plating: acid, cyanide, and alkaline.

A c i d e l e c t r o l y t e s can be used at higher current densities than cyanide or alkaline electrolytes, their efficiency approaches 100%, and they are very stable in operation. Zinc coatings obtained from acid electrolytes adhere well to the base metal but the throwing power of these electrolytes is poor and the deposit has a coarse-grained structure.

C y a n i d e e l e c t r o l y t e s are characterized by a high throwing power. They give coatings of fine-grained structure and high corrosion resistance. The current efficiency is 50 to 75% and lower current densities can be used with such electrolytes. Their shortcoming is their toxicity, as was mentioned earlier in connection with copper-plating.

A l k a l i n e (z i n c a t e) e l e c t r o l y t e s have satisfactory throwing power, are less stable than acid electrolytes, and require heating. The current efficiency is 90 to 95 %.

Acid electrolytes differ widely in composition. The simplest is:

Zinc sulfate	300—400 g/l
Sodium sulfate	40—50 g/l
Aluminum sulfate or aluminum-potassium alums	30—45 g/l
Current density	0.3—1 amp/dm^2
Temperature	15—20°C
pH value	4.0—4.5

Disulfonaphthalene acid salt is added to the electrolyte if a brighter and more lustrous coating is required.

Cyanide electrolytes also differ widely in composition. The following composition is widely used in stationary and rotating-barrel tanks:

Zinc oxide	40—45 g/l
Sodium cyanide	80—85 g/l
Caustic soda	40—60 g/l
Current density	1.5—2 amp/dm^2
Temperature	18—25°C
Current efficiency	70—85%

Cyanide electrolytes are very sensitive to contamination by the salts of iron and lead and by other admixtures.

The composition of alkaline (zincate) electrolytes is:

Zinc oxide	4—12 g/l
Caustic soda	60—90 g/l
Tin chloride ($SnCl_2$ or $SnCl_4$)	0.15—0.25 g/l
Bath temperature	50°C
Current density	0.3—1.2 amp/dm^2
Current efficiency	95%

The dials of pocket- and wristwatches are usually s i l v e r - p l a t e d. A silver layer is characterized by a beautiful color and a mat finish. Only cyanide electrolytes are used for silver-plating dials. The basic electrolyte salts are the complex cyanide salt of silver ($KAg(CN)_2$), and free potassium cyanide (KCN). Potash (K_2CO_3) is added to the electrolyte in order to improve the electroconductivity and to obtain an even silver deposit on the surface.

The bath composition and the working conditions are as follows:

Metallic silver	20—30 g/l
Potassium cyanide	10—17 g/l
Potash	8—10 g/l
Anodes	99, 99% pure
Layer thickness	2—3 μ
Current density	0.3—0.5 amp/dm^2
Holding time	12—16 min
Temperature	Room temperature

The dial silver-coat is applied on an underlayer of brass, tomback, or copper (acid). Silver-plated dials are brightened in ammonia for $\frac{1}{2}$ to 1 min, and coated with a BMK-5 colorless varnish.

G o l d - p l a t i n g is applied to parts of pocket- and wristwatches and alarm clocks. It serves the dual aim of giving the parts an aesthetic appearance and protecting them from corrosion. Gold has excellent chemical resistance and is not tarnished by atmospheric air. It is dissolved only in "aqua regia" (a mixture of hydrochloric and nitric acids in a ratio of 3:1).

Cyanide baths only (gold cyanide, gold chloride or gold fulminate) are used for gold-plating. Gold cyanide is obtained by galvanically dissolving metallic gold in a solution of potassium cyanide through a porous vessel.

Gold chloride is obtained by dissolving metallic gold in aqua regia. The trivalent gold chloride obtained ($AuCl_3$) is then transformed into a complex cyanide salt $K[Au(CN)_2]$ by treating it with potassium cyanide.

Gold fulminate is obtained from gold chloride by dissolving it in hot water and treating it with ammonia (NH_4OH). The precipitate of gold fulminate obtained is dissolved in potassium cyanide, as it is highly explosive in a dry state.

The electrolyte composition and the working conditions are as follows:

Gold (metallic)	10—12 g/l
Potassium cyanide	20—25 g/l
Disodium phosphate	20—25 g/l
Current density	0.10—0.25 amp/dm^2
Temperature	50--60°C
Holding time	5—7 min

Some plants use electrolytes with a gold concentration of 5 – 7 g/l, 2 – 3 g/l of potassium cyanide, at current densities of 0.1 – 0.2 amp/dm^2.

Brass and copper parts whose surface quality does not have to satisfy strict specifications, and for which a thin layer of gold (0.1 μ thick) is sufficient, are gold-plated by simple immersion in a solution (without electrolysis) of the following composition:

Chloroauric acid	0.6 g/l
Disodium phosphate.	6 g/l
Caustic soda	1 g/l
Sodium carbonate	3.0 g/l
Potassium cyanide	10 g/l

The bath is heated to 90°C.

The thickness of the gold layer on movement parts, which are internal parts, must be 0.6 – 0.7 μ, while the thickness of gold on external parts must be between 5 and 7 μ or even 20 μ. External parts are accordingly given several layers, each 1.5 – 2 μ thick and each rubbed and polished in turn. In order to obtain thick layers of high quality, it is recommended that the polarity of the electrodes be periodically reversed.

Fourteen-carat gold can be used for gold-plating instead of pure gold. In this case a solution of copper cyanide is introduced into the electrolyte, and either 14-carat gold anodes or separate pure gold and copper anodes are used. The coatings obtained are reddish and more wear-resistant.

Gold and silver platings must satisfy the additional requirement of metal economy. Standards have been fixed for recoverable and nonrecoverable metal losses. Nonrecoverable losses are those incurred in electrolyte preparation, filtration, slag formation on the anodes, cleaning and polishing of the parts, and rinsing. Recoverable losses include the gold deposited on the work suspensions, the gold coating of parts rejected by inspection, the gold spent in electrolyte analysis, etc.

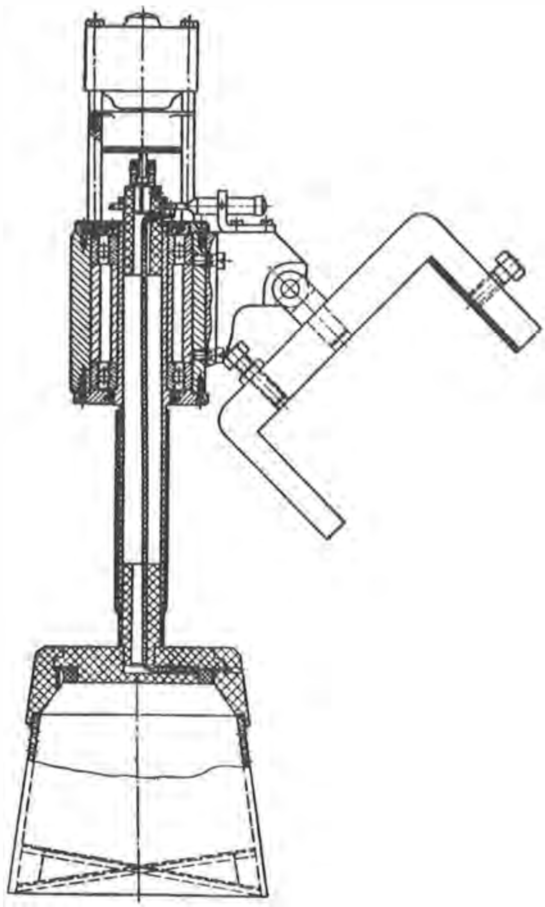


FIGURE 22. General view of a gold-plating installation

Nonrecoverable losses represent 1 to 2 % of the total expenditure and recoverable losses constitute 3 to 30 %, depending on the gold-plating method and the part configuration. When the parts to be gold-plated are hung from a suspended wire frame or held in a brass-wire basket, the amount of recoverable gold deposited on the frames or wire baskets will be equal to or even higher than the amount deposited on the parts themselves. When parts are gold-plated in a barrel or basket whose walls and bottom are made of plexiglass, the gold losses can be zero. A drawing of a gold-plating installation is shown in Figure 22. The plexiglass barrel rotates in the electrolyte during operation.

The recoverable losses in stationary baths are 8 to 12 % on the average.

CHEMICAL COATINGS

The following types of chemical coatings are used in watch production: oxide coatings, phosphate coatings and passivation films.

The oxide coating of the surface of alarm- and wall-clock steel parts in very hot alkaline solutions in the presence of oxidizers is widely practiced as a finishing operation. The oxide-coated surface resists corrosion in a favorable medium only, the oxide film being rapidly destroyed in a moist medium.

Alkaline oxide-coating is performed in a bath of the following composition:

Caustic soda	700—800 g/l
Sodium nitrate	80—120 g/l
Sodium nitrite	80—120 g/l
Temperature	135—145°C
Holding time	Up to 60 min
Film thickness	0.1—0.8 μ

The parts to be oxide-coated are rinsed in cold water and then boiled in a 5% soap solution, after which they are again rinsed in hot water and then in running water, dried at 110–120°C, and rubbed with oil. Rubber gloves and aprons should be used when working with the baths to avoid skin damage.

Brass parts are oxide-coated in solutions of so-called "liver of sulfur", prepared by melting a mixture of sulfur and potash fragments in a ratio of 1:2. A brown color can be imparted by dipping the parts in a solution of liver of sulfur and ammonium chloride in a ratio of 1:2.

The oxide-coating process takes 1 to 2 min.

A bath of the following composition is used for the black oxidation of dials:

Blue vitriol	98 g/l
Calcined soda	48 g/l
Ammonia 25 %	400 cm^3
Temperature	Room temperature
Holding time	3—5 min

The oxide-coated parts are rinsed in cold water and dried in cigarette paper.

Phosphate coatings are phosphate films of low corrosion resistance which adhere well to the base steel and also provide anchorage for organic coatings. Alarm-clock cases made of low-carbon steel which are to be coated by nitroenamel are first phosphate-coated. Phosphate-coating is performed using "Mazhef'" an acid salt of manganese phosphate and iron. The concentration of this salt in the batch is about 30-35 g/l. The bath temperature is

95 to 98°C. The holding time is about an hour, after which the parts are dried, and their surface is mechanically freed from residues.

Passivation. Brass watch-movement parts which do not require electroplating are passivated. After the bright-pickling the parts are treated in a solution of the following composition:

$Na_2Cr_2O_7$	250–300 g/l
H_2SO_4 (sulfuric acid)	80–100 g/l

The solution is at room temperature. The holding time is from 30 sec to 1 min.

Passivation should be followed by a careful rinsing of the parts in cold running water.

ORGANIC COATINGS

Organic coatings are used in watch production mainly for finishing the metallic cases of alarm clocks, automobile clocks, and other watches. Organic coatings are used in the manufacture of pocket- and wristwatches for dial finishing only.

Organic coatings provide protection against corrosion and afford an aesthetic appearance. Organic coatings must well adhere to the metal, have sufficient mechanical strength and elasticity (resist blows and abrasive wear) and show no peeling off or rupture when the part is deformed. The coatings must also be light-resistant, that is, no noticeable color change as the result of exposure to light must be observed over a specified period of time.

Additional requirements (resistance to gasoline, water, oil and to temperature variations) are imposed on the organic coatings depending on the medium in which the product must operate. Paints must be impermeable to moisture in order to protect the metal surface against corrosion. Materials used for organic coatings are classified as primers, fillers, lacquer enamels and lacquers, nitroenamels and nitroglyptal enamels and varnishes, solvents and thinners, and other auxiliary materials*.

The primer is the first layer applied to the metal. It must adhere well both to the metal and to the subsequent layers. The primer layer must be elastic and impermeable to moisture. It is 15 – 20μ thick.

The following are the most widely used primers:

Primer No. 138 (GOST 4056–48). Brown color. Main components: red lead-iron or mummy, yellow lead or zinc chromate, siccative and glyptal varnish No. 154. The primer is applied to the metal by spraying or brushing at 18–20°C, and diluted by a coal-tar solvent or xylene (10–20% by weight).

This primer is very stable with respect to temperature variations (between -40 and +40°C), resists blows and deformation and dries at 100 to 110°C in 30 min. Drying at usual temperatures will give an unstable coating film, regardless of the drying time.

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* Orgavtoprom Institute, Bulletin No. 1, 1953.

Nitroglyptal primer No. 147 (TU MKhP 1945-1949). Brown color. Glyptal base with added colloidal xylene base and a plastifier. It is used as a primer for less critical parts. Its properties are rougly the same as those of primer No. 138, with the exception that it is diluted by solvent No. 646 or RDV. It is dried at 60 to 65°C for not more than 35 min.

Nitroglyptal primer No. 148 (TU MKhP 2032-49). Black color. Used for parts subjected to frequent contamination and dust. Made from a nitric base with the addition of lacquer No. 154. Soot is added to the primer as a pigment. Primer 148 is similar in other respects to primer 147.

Fillers are applied to the surface for smoothing purposes. Filler is applied on the primer and is sanded after it dries. Its mechanical strength is lower than that of the primer, and it is accordingly applied in a thick layer (25-30 μ). The most widely used glyptal-base fillers are No. 175 and No. 185 (TU MKhP 331-48). They are applied on the primer and serve as an undercoat for the cover paint. The filler is diluted by a coal solvent (10–25% by weight) and is sprayed on at 18 to 20°C. It is dried for an hour at 100 to 110°C. Filler is applied on No. 138 primer and differs from the primer in its lower oil content and higher pigment content.

No. 175 is pink, and No. 185 is gray.

Lacquer enamels and lacquers. Coating paints, laquer enamels among them, must have high covering power (covering power is the capacity to cover the metal or earlier coating so that they are not visible through the paint film). Lacquer paints are suspensions of pigments in various resins, oils and lacquers, with solvents (and sometimes also plastifiers) added.

Pigments are insoluble mineral dyes introduced into the paint in a finely divided form and which remain in a suspended state. Every paint has a liquid phase (solvent), which evaporates during drying, and a solid phase which consists of resins, oils, dyes and plasticizers and forms the film in drying. A film is called reversible if it can be reconverted to the original paint by dissolving it; and it is called irreversible if it polymerizes in drying.

Lacquer paints form irreversible films. These films nevertheless gradually deteriorate with time, a process known as aging. The physicochemical properties of the film deteriorate during aging under the influence of heat, humidity, and especially sunlight, until the film is destroyed and peels off.

Oil-paint films have many advantages over nitrofilms: better adhesion to the metal, greater elasticity (but lesser hardness), better temperature resistance (can stand up to temperatures as high as 150°C). Oil-paint films swell in water, however.

Urea formaldehyde enamels (VTU MKhP 2531-51) are mixtures of pigments in urea formaldehyde resin with the addition of alkyd resin and RKB-1 solvent. These enamels are being used of late for painting the cases of alarm and other clocks, supplanting the nitroenamels, because of a number of engineering and operational advantages. Enamels are applied by spray guns at 18 to 20°C. They can also be applied by dipping. The parts are dried at 80 to 90°C for 20 min and at 120°C for a further 40 min.

During this drying process, the butanol in the solvent evaporates slowly from the film, leaving a smooth surface free of fine pits. The enamel film is as hard as glass and is at the same time sufficiently elastic. Enamel can be applied directly on the metal in two layers, thus satisfactory adhesion is achieved. Colored enamels are produced: black (U-417, U-418), blue (UZ-16), apple-green (UE-11), ivory (UE-2), green (UE-13).

UVL-1 lacquer is colorless (VTU MKhN 2532-51). It is a solution of urea formaldehyde resin and alkyd resin in organic solvents. It is used for lacquering surfaces coated by urea formaldehyde enamels. Methods of application and drying conditions are identical with those for the paints.

Nitroenamels are colloidal solutions of nitrocellulose (colloidal xylene) and resin in volatile organic solvents, with plasticizers and pigments added. Nitroenamels are cover paints and are applied on the primer and filler, or directly on the metal after its surface has been phosphated for better adhesion. The main advantage of nitroenamels over oil enamels lies in their rapid drying (60 min maximum) under natural conditions, 30 to 40 min are sufficient if they are heated to 30 to 40°C. The nitrofilm can be sanded and polished. Nitroenamels have a good "covering power", and are accordingly applied in a thinner layer than oil enamels. The index to the covering power is the amount of paint, in grams, required to cover a square meter of surface (not taking into account the weight of the solvent). Black nitroenamel has the lowest index (20 g/m^2) and is applied in one layer. Bright-colored enamels, with indexes reaching 60 g/m^2, require two or three layers. A nitroenamel having an index higher than 60 g/m^2 would not be suitable. Nitroenamels require fine grinding of the pigments. Nitroenamels resist sunlight relatively well, but their resistance to blows is poor, they have low elasticity and poor adhesion, and are permeable to water. Nitroenamels are applied by spraying at 18 to 20°C and are diluted by solvent No. 646, 647 or RVD in a ratio of 80 to 120 parts to 100 parts of enamel. Oil-paint solvents are not suitable for nitroenamels. DM and DMU (TU MKhP 1281-45 and GOST 5406-50) nitroenamels in various colors are used for the decorative coating of alarm-clock and automobile-clock cases. They are applied in two layers to a phosphated surface without subsequent buffing. White enamel (TU KhP 519-41), which dries in 30 min, is used for coating the dials of large clocks.

Solvents and thinners. Thinners generally used for oil paints are coal-tar solvents (also known as solvent naphtha), white spirit, benzene, toluene, RKB-1, and more rarely turpentine. Thinners used for nitroenamels are acetone, solvents Nos 646, 647, 648, and RDB.

Solvent naphtha (GOST 1928-50) is a product of the distillation of coal tar and is one of the best solvents for oil and glyptal paints (used mainly with the latter). It is sometimes used in a mixture with turpentine. Solvent naphtha is a colorless transparent liquid.

White spirit (OST 3134–46) is a product of petroleum distillation. It is used for diluting oil paints. White spirit is a colorless transparent liquid, nonexplosive, and relatively cheap.

Turpentine (GOST 1571-42) is a product of the dry distillation of wood, and is one of the best solvents for oil paints. It gives a better luster to the film but its use is restricted by its high price.

Benzene (OST 10463-39) is a product of the dry distillation of coal. It is a colorless liquid of characteristic odor and is a very good solvent for fats, resins, oils and rubber.

Toluene (OST 10464-39) is a product of the dry distillation of petroleum residues. It is a colorless liquid of characteristic odor and is used as a solvent for oil paints and for the preparation of drugs, saccharin, etc.

The RKB-1 thinner (TU MKhP 2533-51) consists of a mixture of xylene and butanol in a ratio of 1:1, and is used for diluting urea formaldehyde enamels and lacquers.

Industrial acetone (GOST 2768-44) is a product of dry distillation of wood, acetic-acid salts and many other organic substances. It is a colorless liquid of characteristic odor, and is used for diluting nitroenamels.

Solvents Nos 646, 647, 648 (GOST 6530-51, 4005-48, 4006-48) are mixtures of volatile organic liquids, esters, alcohols, aromatic carbohydrates, etc.

Solvents must be colorless, transparent and homogeneous. No 647 possesses the best properties. It is used for diluting nitroenamels and nitrolacquers.

RDV thinner (GOST 4399-48) is a mixture of aromatic carbohydrates, ethers, ketones, and aliphatic alcohols. It is used for diluting nitroenamels, nitrolacquers and nitrofillers and for washing off nitrocoatings. It can replace solvent No. 646, and is more active than the latter.

Washing compounds are used for degreasing parts and removing traces of corrosion. Washing usually precedes application of organic coatings.

Compound No. 1120 (TU MKhP 271-51) is an aqueous solution of phosphoric acid with alcohol and hydroquinone added. It contains 30 % phosphoric acid, 20 % ethanol, 5 % butanol, 1 % hydroquinone, and 44 % water. Alcohols are introduced for better wetting of the surface and better spreading of the compound. The compound is used for removing rust films and mineral-oil traces. It is applied manually with a brush, is left on the surface for 2 to 5 minutes till it dissolves the rust films and the mineral-oil traces, and is then washed off with hot water. The part is then washed with compound No. 108, which removes moisture and neutralizes the traces of phosphoric acid still left. Compound 108 is an ethyl alcohol with liquid ammonia added.

Ethyl (ordinary) alcohol (GOST 5962-51) is used for the final washing or rubbing of the parts.

Formula No. 1084 is used for degreasing metallic parts before painting and is sprayed on in mechanized washing machines. It consists of 50% caustic soda, 20% calcined soda, and 30% trisodiumphosphate. The compound has good washing properties. Trisodiumphosphate favors the emulsification of the oils and their washing away from the parts.

Rubbing **materials.** Glossy surfaces are rubbed using chamois (suede) leather, sea sponges and artificial sponges, towels, gauze or flanel cloth.

Rubbing materials must be clean (free from mechanical contamination), as otherwise scratches and fine (hair) cracks might appear on the part surface. Flax towels are better than cotton ones, as the latter leave hairs on the rubbed surface.

Chamois leather, made of deer skin, is the best rubbing material. It absorbs moisture and can be washed in soapy water and dried. Flanel cloth is also a good rubbing material. Both materials must be free from hard inclusions, and therefore must be carefully cleaned of such after washing and drying.

Sea sponges and artificial (rubber) sponges can also be used for rubbing. Sponges must satisfy the same requirements as other rubbing materials with respect to hard inclusions which could scratch the surface being rubbed. The purity of the compound must be checked, and the presence of sodium chloride (common salt), which favors corrosion, should not be allowed.

SAFETY RULES IN HANDLING ORGANIC COATINGS

All organic coatings are more or less dangerous, both because of their inflammability and their toxicity. Organic coatings are inflammable as such; the vapors of the volatile solvents can form explosive mixtures with air which could be set off by a match or a spark from an electric switch. Paints containing drying oils and turpentine are in some cases subject to spontaneous combustion: thus, rags impregnated by drying oil and lumped together may ignite after a certain time.

Spontaneous combustion occurs as a result of the intense oxidation of the drying oil by the oxygen in the air over a large rag area. The corresponding increase in the temperature of the rag lump (the heat is not carried off at a sufficient rate by the surrounding medium) causes the rags to ignite when a certain temperature is reached. The requirement that close watch be kept on the storage conditions of drying materials and the state of equipments stems from these dangers.

Solvents do not ignite spontaneously under ordinary conditions. Their ignition temperature is between 150 and 400°C. Solvent vapors mixed with air produce explosive mixtures only at certain critical concentrations (different for each mixture). The most dangerous are: acetone, benzene, toluene, and light gasoline.

Concentration of solvent vapors and formation of explosive mixtures may be avoided by the correct design of the ventilation system and by the proper handling of the empty packing materials which might contain solvent traces. Good ventilation, meaning a constant inflow of fresh air, is essential in all plants working with organic coatings in order to afford maximum security in the use of the materials. Factory hands working in spray booths with especially toxic solvents should use respirators.

Organic-coating storerooms must satisfy all fire-safety requirements.

Chapter X

ASSEMBLY AND ADJUSTMENT OF WATCHES

Assembly is the last stage in the production process and the assembled watches must satisfy both the All-Union Government Standards and the departmental specifications.

The sequence of assembly operations and the means and methods for performing each operation are established in advance, as was the case with the machining process, and the process design must specify which parts reach the assembly shop as separate units and which as subassemblies.

Assembly-process design is based on the part drawings and specifications and on the plant data available.

A high assembly rate is attained by using special equipment and fixtures and interchangeable parts and subassemblies. Fixed time-rate assembly-line work is possible only if the parts are completely interchangeable.

Interchangeability means that any part or subassembly can be replaced without additional processing while maintaining the operational requirements of a given subassembly or mechanism.

Interchangeability does not, however, exclude additional adjustment of the parts during their assembly (adjustment is the positioning of matched parts in a manner which ensures their correct functioning in the movement). The use of a regulator within the watch thus allows the watch rate to be adjusted within certain limits without altering the dimensions of the balance and hairspring.

Interchangeability of parts eliminates fitting time and makes it possible to carry out the operations at a fixed rate and to employ semiskilled workers.

Interchangeability is also necessary to allow subsequent repairs. It is much easier to replace a broken part by an identical new part than to repair the broken part. The identical new part will, as a rule, give better performance, especially when parts such as the balance with staff and hairspring, or the pallet lever with guard pin, are replaced.

Interchangeability of parts and subassemblies is achieved by accurate mechanical working and heat treatment. Interchangeability is classified as geometrical or physical. Two mainsprings may be interchangeable geometrically (or identical dimensions) but still differ in their torque, as an incorrect heat treatment can lead to a lower torque. These springs will not, therefore, be physically interchangeable.

Dimensional calculations, which give the actual clearances or interferences (negative allowances) to be anticipated in assemblies, make it possible to check whether the planned production process ensures geometrical interchangeability, and whether the movement components will interact correctly. Any necessary alterations are introduced on the basis of the results of these calculations.

Limit calculations are dimension calculations based on the extreme values of the dimensions. *Theoretical-probability* calculations are calculations which take into account the probability of dimensional deviations.

Watch-production planning is based mainly on limit calculations and theoretical-probability calculations are used only in special cases. The calculations are simply a rational statement of the dimensions and tolerances on the drawing. The principles of the shortest possible dimension chains, and the coincidence of the design, reference, and measuring surfaces should be observed.

DIMENSIONAL CHAINS*

Consecutively adjoining dimensions which connect the surfaces of parts form a chain of dimensions, or a dimensional chain.

The chain is closed if there is a resultant dimension. The aim of dimension calculations is to find the value of the resultant dimension.

Dimensional chains (or diagrams) can have various shapes and be made up of any number of dimensions more than 2. They are usually classified as *linear, plane or spatial chains.*

A linear chain is composed of mutually parallel linear (not angular) dimensions.

A plane chain is made of nonparallel linear dimensions, or of linear and angular dimensions which all lie in the same plane.

A *spatial* dimensional chain (diagram) is formed by nonparallel linear dimensions, or linear and angular dimensions, which do not all lie in the same plane.

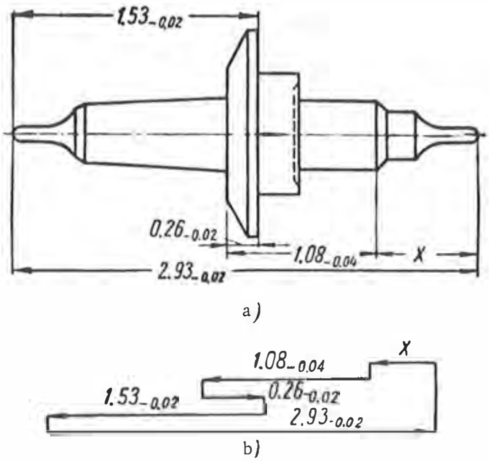

FIGURE 1. Pocket-watch balance staff:

a-drawing; b-linear dimensional-chain diagram.

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* Bezmenov, A. E. Raschet razmernykh tsepei (Dimensional-chain Calculations). — NIIChASPROM, 1950.

Linear chains can be formed by the dimensions of one part or those of several parts.

Figure 1 shows a pocket-watch balance staff whose dimensions (Figure 1, a) form a linear dimensional chain. The dimensional-chain diagram is given in Figure 1, b. Dimension x is the resultant. Dimension diagrams are usually represented in vectorial form to an arbitrary scale with a vector corresponding to each dimension. Stepped representation of the dimensions ensures easier reading. Both the direction of the resultant vector and its position in the dimensional chain are arbitrary.

Designating positive dimensions by capital letters and negative dimensions by small letters, we can write the following equation:

$$x=(A+B+C+\ldots+M)-(a+b+c+\ldots+m).$$

The limiting values of the resultant x will be

$$\begin{aligned} x_{max} &= (A_{max}+B_{max}+C_{max})-(a_{min}+b_{min}+c_{min}), \\ x_{min} &= (A_{min}+B_{min}+C_{min})-(a_{max}+b_{max}+c_{max}). \end{aligned} \tag{1}$$

The following expression is obtained by subtracting the second expression from the first:

$$\begin{aligned} x_{max}-x_{min} = {} & (A_{max}-A_{min})+(B_{max}-B_{min})+(C_{max}-C_{min})+ \\ & +(a_{max}-a_{min})+(b_{max}-b_{min})+(c_{max}-c_{min}). \end{aligned}$$

The difference between the limiting values of the dimensions being equal to the tolerance δ, this last expression can also be written in the form

$$\delta_x=\delta_A+\delta_B+\delta_C+\ldots+\delta_a+\delta_b+\delta_c \tag{2}$$

or finally as

$$\delta_x=\sum_{i=1}^{i=n}\delta_i,$$

where δ_x = the tolerance on the resultant dimension;
δ_i = the tolerance of the i-th dimension of the dimensional chain;
n = the number of dimensions in the chain.

The tolerance on the resultant dimension of a linear dimensional chain δ_x is thus seen to be the sum of the absolute values of the tolerances on all the dimensions (both positive and negative) in the chain.

It follows that the tolerance δ_x is smaller, the smaller the number of dimensions in the chain. According to the "principle of the shortest dimensional chain" the number of dimensions determining the assembly characteristic of a product should be equal to the number of parts in the chain.

Let us consider the dimensional chain shown in Figure 1. The resultant dimension x is the length of the balance-staff journal. According to (1)

$$x_{max} = 2.93 + 0.26 - 1.04 - 1.51 = 0.64 \text{ mm};$$
$$x_{min} = 2.91 + 0.24 - 1.08 - 1.53 = 0.54 \text{ mm};$$
$$\delta_x = x_{max} - x_{min} = 0.64 - 0.54 = 0.10 \text{ mm}.$$

This result can be checked by formula (2)

$$\delta_x = 0.02 + 0.02 + 0.04 + 0.02 = 0.10 \text{ mm}.$$

The tolerance on the resultant dimension x is not given in the drawing. The linear dimensions in Figure 1 are disposed so that the measuring surface coincides with the design surface, and the dimensions can be easily measured using a watch micrometer or dial gage.

The dimension diagram for assemblies determines the manufacturing process to be used.

Figure 2 represents a longitudinal section of the watch movement through the axes of the third and fourth wheel, and Figure 3 (a and b) shows the linear dimension chains for two process variants.

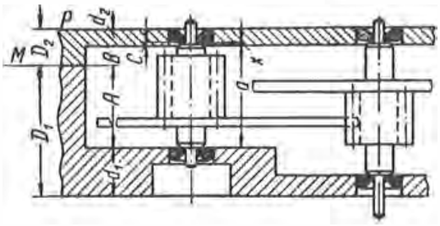
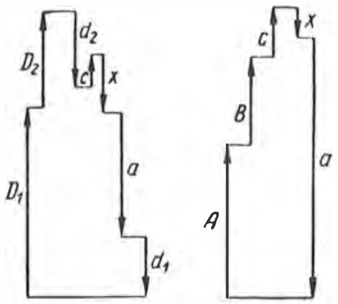


FIGURE 2. Watch-movement section



a) b)

FIGURE 3. Linear dimensional-chain diagram:

a–first process variant; b–second process variant.

$D_1 = 2.7_{-0.01}$	$A = 1.3^{+0.01}$
$D_2 = 1.2_{-0.01}$	$B = 0.7^{+0.01}$
$d_2 = 0.50_{-0.015}$	$C = 0.15^{+0.01}$
$c = 0.15^{+0.01}$	$a = 2.13_{-0.02}$
$a = 2.13_{-0.02}$	
$d_1 = 1.40_{-0.015}$	

An axial clearance x between the pinion-journal shoulder and the jewel face is necessary, in addition to the radial clearance in the jewel, in order to enable the third-wheel pinion to revolve freely.

We will calculate the dimensional chain resulting from the first process variant (Figure 3, a), where the plate and bridges are machined using equipment available for watch production. The face is machined to dimensions D_1 and D_2 on the S-188 machine to an accuracy of 0.010 mm. The S-50 machine is used for machining the recesses to dimensions d_1 and d_2 to an accuracy of 0.015 mm.

Using formula (1), we obtain the following limiting values for x:

$$x_{max} = (2.7 + 1.2 + 0.16) - (0.485 + 2.11 + 1.385) = 0.08 \text{ mm}.$$
$$x_{min} = (2.69 + 1.19 + 0.15) - (1.40 + 0.5 + 2.13) = 0;$$
$$\delta_x = x_{max} - x_{min} = 0.08 - 0 = 0.08 \text{ mm}.$$

The clearance in the assembly must lie within the limits from 0.02 to 0.07 mm according to specifications; thus

$$x_{max} = 0.07 \text{ mm and } x_{min} = 0.02 \text{ mm and } \delta_x = 0.05 \text{ mm}.$$

It follows that the processing method described will lead to a certain amount of rejects. The proportion of rejects can be calculated using the theoretical-probability method. We assume that the scatter of dimensions for each link in the chain conforms to the law of normal distribution. It follows from the probability theory that the scatter in the resultant dimension will likewise conform to the law of normal distribution, and that its range, or tolerance δ_x will be equal to $6\sigma_x$. The standard deviation will therefore be

$$\sigma_x = \frac{\delta_x}{6} = \frac{0.08}{6} = 0.013 \text{ mm}.$$

We will plot the normal-distribution curve for the given case (Figure 4). The area which represents the probability of obtaining acceptable assemblies can be split into two parts (A and B). The shaded areas represent the probability of obtaining rejects. The probability of obtaining acceptable assemblies can be determined using the formula

$$\omega = 0.5\,[\Phi(z_A) + \Phi(z_B)], \qquad (3)$$

where the values of $\Phi(z)$ are taken from the table in Appendix 1 and $z = \frac{x_0}{\sigma}$. We obtain for x_A = 0.02 mm, x_B = 0.03 mm, and σ_x = 0.013 mm

$$z_A = \frac{x_A}{\sigma_x} = \frac{0.020}{0.013} = 1.54;$$
$$z_B = \frac{x_B}{\sigma_x} = \frac{0.03}{0.013} = 2.30.$$

From the same table $\Phi(z_A)$ = 0.8764, and $\Phi(z_B)$ = 0.9786. Substituting in (3) we obtain: w = 0.5(0.8764 + 0.9786) = 0.9275.

The probability of obtaining acceptable assemblies is thus 92.75 %. The remaining 7.25 % of the assemblies must be adjusted, that is the dimension C must be altered by displacing the jewel. This is the procedure actually used in the assembly shops of watch plants. This type of adjustment does not require chip removal or shape alteration, as in the case with fitting operations, and its use is advisable where incomplete interchangeability is practiced.

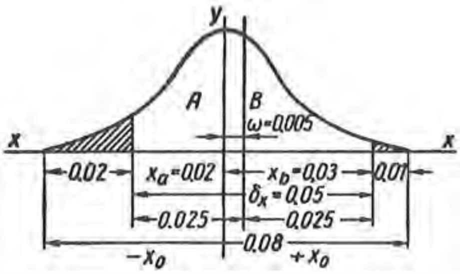


FIGURE 4. Dimension-distribution curve for the first process variant

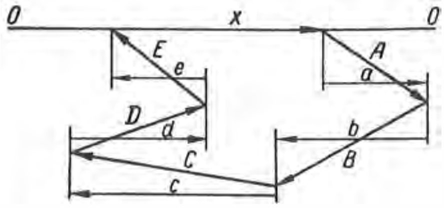


FIGURE 5. Diagram of a plane dimensional chain

If it is required to achieve complete interchangeability and to observe the clearance limits of 0.02 – 0.07 mm, the plate and bridges should be machined according to the second process variant (Figure 3, b). Here the recesses are machined to dimensions A and B from the reference surfaces M, or they are machined in the same chucking as the surfaces M themselves. The machining accuracy for dimensions A and B is higher than the accuracy of machining dimensions d_1, d_2. The dimensional chain in the second variant is the shortest possible, as it is made up of four dimensions for the four parts: plate, bridge, jewel, and pinion. The maximum and minimum values of the resultant are (according to formula (1)):

$$x_{max} = 1.31 + 0.71 + 0.16 - 2.11 = 0.07 \text{ mm};$$

$$x_{min} = 1.30 + 0.70 + 0.15 - 2.13 = 0.02 \text{ mm}.$$

Whence

$$\delta_x = 0.07 - 0.02 = 0.05 \text{ mm}.$$

The limit calculation shows that all assemblies machined according to the second variant will be acceptable. The design of machines which will process plates and bridges according to this variant is a matter of time only.

Watch-movement dimension calculations frequently reduce to the calculation of a plane dimensional chain. Such a chain can be solved either by projection on a line, by a combined method, by means of a coordinate system, or analytically.

The first two – the projection and the combined methods – are used in watch production.

P r o j e c t i o n is a method of reducing a plane dimensional chain to a linear chain. This is done by projecting all the dimensions on some line (direction) which can be the resultant (x) direction, or any other direction which is not perpendicular to any of the dimensions. By connecting the parallel dimensions thus obtained, we obtain a linear chain closed by the dimension(x). Figure 5 shows the projection of the plane dimensional chain $ABCDEX$ as the linear chain $abcdex$.

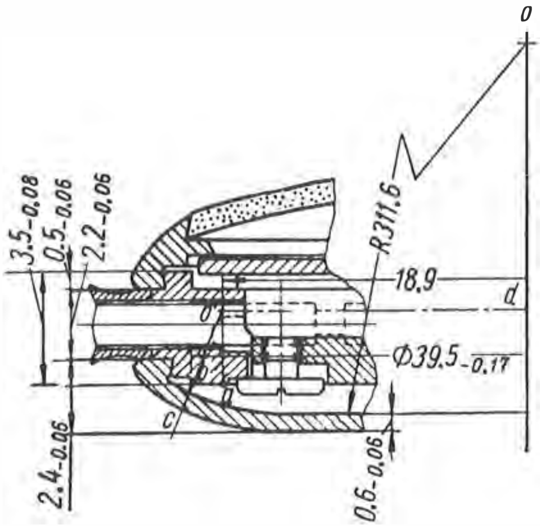


FIGURE 6. Sectional view of the K-36 pocket watch through the winding-stem axis

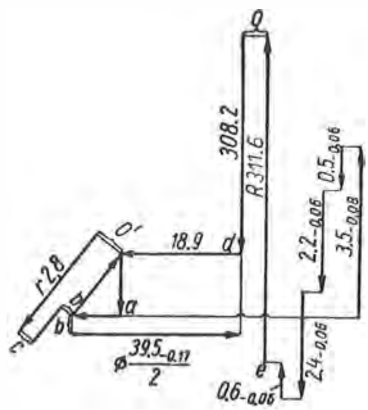


FIGURE 7. Schematic diagram of the plane dimensional chain corresponding to Figure 6

This method is rarely used in watch-movement calculations. Plane dimensional chains are usually calculated by combined methods, that is by using the graphical-analytical method.

As an example we will the assembly (operation) of the middle and back of K-36 pocket watches. Figure 6 is a section of the watch through the winding-stem axis. The clearance bc must be positive under all assembly conditions. The corresponding dimensional chain (Figure 7) is made up of horizontal, vertical, and inclined dimensions. The clearance (see Figure 7) is

$$x = o'c - o'b = 2.8 - \sqrt{ab^2 + o'a^2}. \quad (4)$$

The distance $o'o$ = 311.6 - 2.8 = 308.8 mm, and therefore

$$od = \sqrt{o'o^2 - o'd^2} = \sqrt{308.8^2 - 18.9^2} = 308.2 \text{ mm}.$$

The values of ab and $o'a$ are determined from the two linear dimensional chains. The horizontal linear chain determines the magnitude of ab

$$ab = \frac{39{,}5_{-0{,}17}}{2} - 18{,}9 = 0{,}85_{-0{,}085}.$$

The vertical linear chain determines the value of $o'a$:

$$o'a_{nom} = (311.6 + 0.6 + 3.5) - (308.2 + 2.4 + 2.2 + 0.5) = 2.13 \text{ mm};$$
$$o'a_{max} = (311.6 + 0.6 + 3.5) - (308.2 + 2.34 + 2.14 + 0.44) = 2.31 \text{ mm};$$
$$o'a_{min} = (311.6 + 0.54 + 3.42) - (308.2 + 2.4 + 2.2 + 0.5) = 1.99 \text{ mm}.$$
$$o'a = 2.13^{+0.18}_{-0.14}$$

Substitution of the values obtained for ab and $o'a$ in expression (4) gives

$$x_{nom} = 2.8 - \sqrt{0.85^2 + 2.13^2} = 2.8 - 2.29 = 0.51 \text{ mm};$$
$$x_{max} = 2.8 - \sqrt{0.76^2 + 1.99^2} = 2.8 - 2.13 = 0.67 \text{ mm};$$
$$x_{min} = 2.8 - \sqrt{0.85^2 + 2.31^2} = 2.8 - 2.47 = 0.33 \text{ mm}.$$

The clearance x thus lies within the limits 0.67 and 0.33 mm, and is therefore always a positive clearance. The assembly tolerance will be δ_x = 0.67 − 0.33 = 0.34 mm.

Dimensional-chain calculation thus makes it possible to establish the most rational manufacturing and assembly processes for the watch movement.

SUBASSEMBLIES

Watch subassemblies are classified into the following groups according to their assembly criteria: plates and bridges with their pins, screws, jewels and sleeves; wheels and pinions; barrel, barrel cap, barrel arbor and mainspring; pallet lever and balance; keyless work and hand-setting parts and external parts.

We will consider several characteristic elements of the assembly of plates and bridges, gear pairs, the barrel and the escapement regulator.

Press-mounting the Sleeves, Pins, and Jewels in the Plate and Bridges

Figure 8 shows the design of detachable joints between plate and bridges. The bridge holes for the pins (2) have 0.01–0.015 mm clearance, and those for the sleeve (1) have 0.1–0.15 mm clearance. Pins up to 1 mm in diameter are fitted into the plate with a negative allowance of 0.01–0.02 mm, corresponding to medium and heavy interference fits (GOST 3047-47). The pins accurately position the bridge on the plate in the horizontal plane and ensure the coaxiality of corresponding holes in the plate and bridge. The pins must therefore be fitted without slant, and the bridges are assembled, again without slant. The bridge is fastened to the plate by screw (3) and sleeve (1). The sleeve is fitted into plate holes with 0.010–0.015 mm negative allowance, corresponding to a light drive fit. This type of bridge-fastening arrangement is used in order to prevent damage to the expensive plate in case the thread is stripped. The sleeve is pressed into the plate with sufficient force to ensure that the screw can hold the bridge tightly to the plate without disturbing the fit of the sleeve or displacing it.

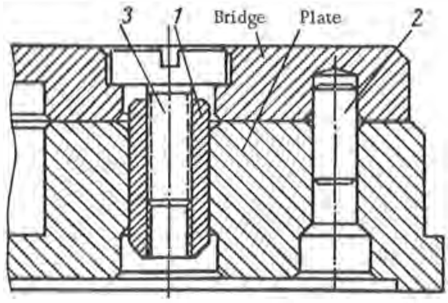


FIGURE 8. Bridge-to-plate fastening system

Pins and sleeves are pressed into the plate by means of a die on an S-10 bench-type power press (Figure 9).

Technical data, S-10 press

Capacity, kg	500
Stroke, mm	15
Strokes per minute	300–500
Distance from ram to press bed, mm	40–175
Dimensions, mm	250×280×450
Weight, kg	30

The "Pobeda" wristwatch plate has six sleeves (S_1-S_6) and eight pins (S_7-S_{15}) pressed into its bridge side (Figure 10). The pressing force is checked by means of a special device and the fitting height, by a dial gage on a vertical post. Both inspections are carried out by random sampling: 5% of each batch are examined.

Jewel bearings are pressed into holes in the plate and bridges which have a negative allowance between 0.010 and 0.030 mm, depending on the hole diameter. The average negative allowance for 1.2 mm diameter jewels is 0.015 mm, corresponding to a light drive fit.

Jewel setting is a crucial operation, and the fits have been established on the basis of considerable experimental work. The stones used are synthetic rubies which, being more brittle than metals, sometimes break if the negative allowance exceeds 0.030 mm.

In order to reduce the possibility of breaking in press assembly with the required negative allowance, the entering chamfer of the jewel is rounded off (Figure 11) and the pressing force therefore increases only gradually.

The jewel must tightly adhere to the hole wall on its entire cylindrical surface (Figure 12).

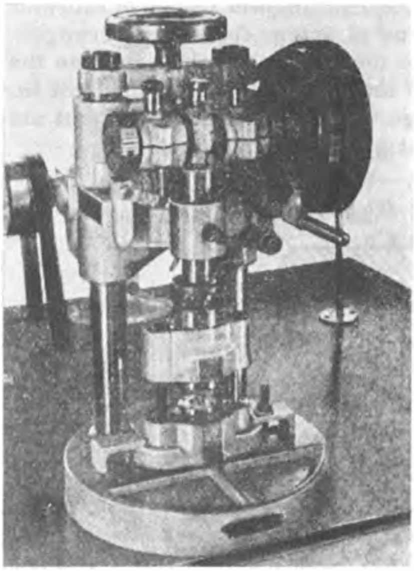


FIGURE 9. S-10 press

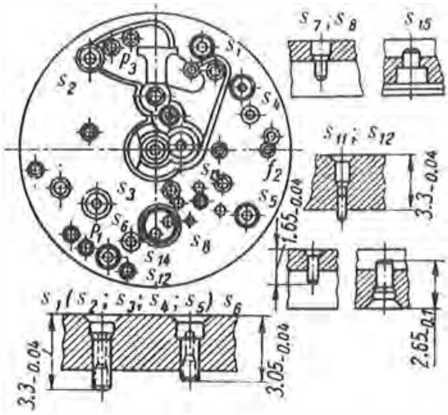


FIGURE 10. Plate with sleeves and pins pressed in

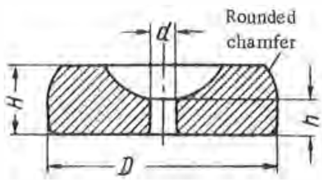


FIGURE 11. Through-hole jewel

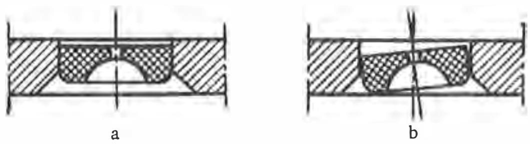


FIGURE 12. Jewel setting in plate and bridges: a—correct; b—incorrect.

Jewels are pressed into their respective seats on S-195 presses (Figure 13). The press is driven by a 0.07 kw, 3000 rpm electric motor. The motor drives shaft (4) through the worm and wheel (2, 3) and key (5) (Figure 14). The flat cam (6) on shaft (4) acts on lever (7) which communicates a downward motion to the ram (1). Ram and lever are returned to their initial position by a spring.

The upper part of the ram has a micrometric scale with divisions of 0.005 mm. Pins and sleeves that require very light assembly forces can be fitted on this press.

Pressing-in is followed by an inspection of jewel intactness (no fractures or cracks are allowed), depth and tightness of the fit, and alignment.

All plate and bridge jewels are inspected, after their setting, using a magnifying glass (5×). A microscope of 16× to 32× magnification is used in dubious cases.

The depth of the fit is inspected using a dial gage or a watch micrometer, mounted on a vertical post.

Fit tightness is checked by means of special devices.

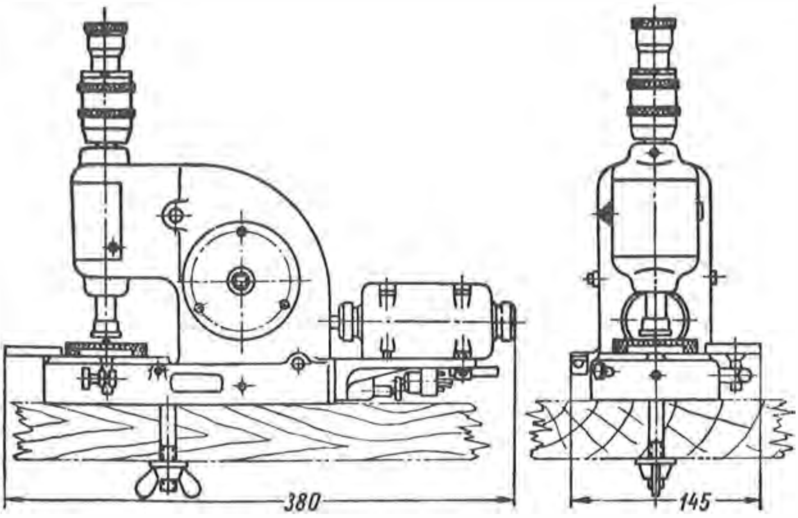


FIGURE 13. S-195 press

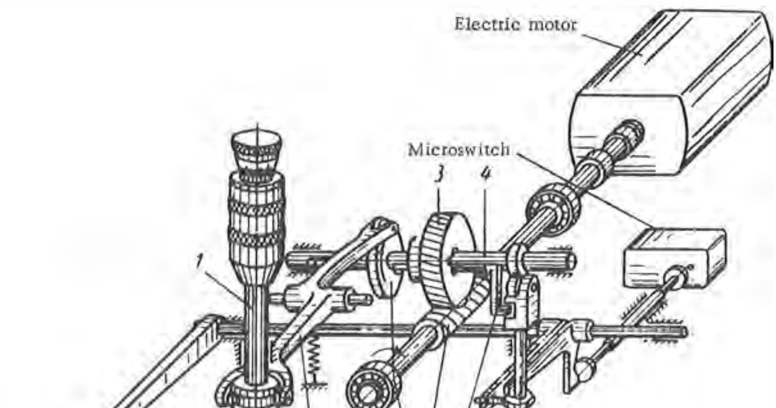


FIGURE 14. Kinematic diagram of the S-195 press

Wheel-pinion Assembly

A characteristic feature of the assembled wheel and pinion is the relatively small wheel thickness compared with the fitting-hole diameter (Figure 15). This results from the fact that the moments transmitted in watch movements are very small and the wheels are therefore made as light as possible in order to minimize friction losses.

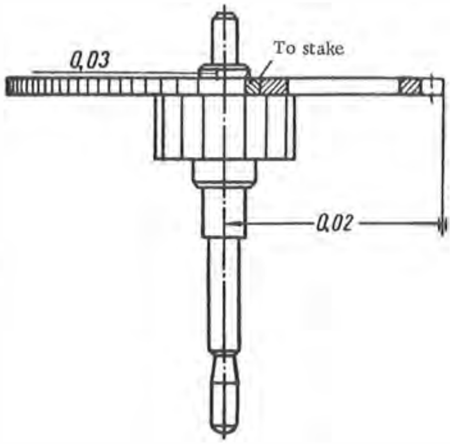


FIGURE 15. Center wheel and pinion

The tightness of the wheel fit on the pinion in the gear-pair subassemblies must be such that the wheel will not slip on its shoulder, and that the radial and face run-outs will not exceed the tolerances specified.

The third and fourth wheels, which transmit very small moments, are set on the pinion with a negative allowance of 0.0–0.01 mm. Larger negative allowances increases the radial and face run-outs.

The center wheel, which transmits a larger moment than that transmitted by the third and fourth wheels, is staked to the pinion shoulder (in addition to the negative allowance), although the staking increases the radial and face run-out for the wheel (see Table 1). As the escape wheel works in impact it is also staked even though it transmits small moments.

TABLE 1

Permissible radial and face run-out for "Pobeda" wristwatches

Subassembly	Run-out, mm	
	Radial	Face
Center wheel	Up to 0.02	Up to 0.03
Third and fourth wheels	" 0.015	" 0.02
Escape wheel	" 0.010	" 0.02

Narrow fitting tolerances are imposed on the parts in order to ensure the reliable setting of the toothed wheels on the pinions and mimimum radial and face run-out. The central hole of the wheels is die-shaved with a tolerance of 0.005 mm on the diameter and 0.005 to 0.01 mm run-out relative to the wheel circumference.

Pinions are machined on Swiss-type automatic screw machines with a fitting-diameter tolerance of 0.005 to 0.010 mm.

The assembly of the wheel and pinion consists in fitting the wheel on the pinion, staking, alignment of the wheel in the face plane, checking the assembly tightness and the radial and face run-out.

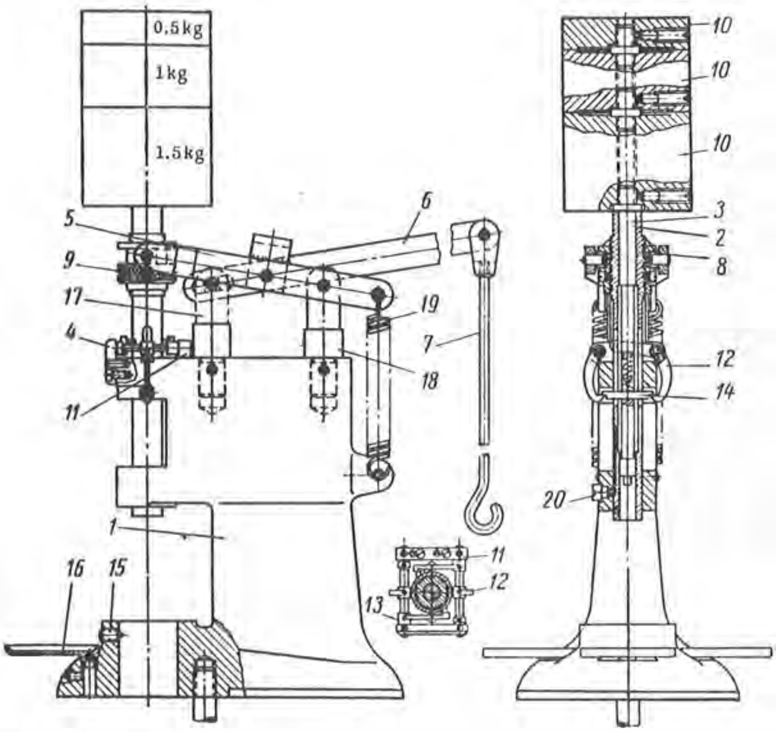


FIGURE 16. D-246 pedal-operated press

Wheels are pressed on the pinions using hand- or pedal-operated table presses. The D-246 pedal-operated table press is the most versatile press for this type of work, and its design is the most advanced. It is used both for fitting the wheels on pinions and for fitting the balance on its staff. Staking can be carried out in the same operation and this arrangement is used, for example, in assembling the center-wheel subassembly.

The D-246 press (Figure 16) comprises a cast-iron body (1), a hollow spindle (2), a plunger (3), a fork (5) and a lever (6), the last two being linked by an adjustable joint.

Fork (5) is connected through stones (8) to nut (9) which is screwed on the spindle (2). Lever (6) is connected to the pedal through rod (7).

Weights (10) are mounted on the upper end of plunger (3). Bracket (11), mounted on the upper face of the body (1), and plate (4), fastened to the front of the body, carry two rods which in turn mount the pawls (12) and the levers (13).

Plunger (3), together with weights (10), is held in the upper position by pin (14) which is supported on the pawls (12).

An exchangeable die is inserted in a hole in the lower part of the body, and is fastened in place by screw (15). Three trays (16) which hold the two parts and the assembled subassembly, are fastened to the lower part of the body. Fork (5) and lever (6) are mounted on supports (17) and (18). Spring (19) holds the spindle (2) in the upper position. Pressing and staking punches are fastened in the lower part of the hollow spindle and the plunger, respectively.

The pinion (or staff) is placed on the die using pincers and the wheel to be mounted is placed on it. When the pedal is pressed, fork (5) lowers spindle (2), and the spindle punch presses the wheel onto the pinion. Simultaneously, the lower face of nut (9) engages the pins on the levers (13), and these cause the pawls (12) to release pin (14). Plunger (3) falls, under the action of weight (10), strikes punch (6) (see Figure 17) and stakes the assembly. The impact is adjusted by changing the weights. The spindle travel is adjusted by nut (9), and its lift is limited by screw (20). The production rate is 4000 subassemblies per shift.

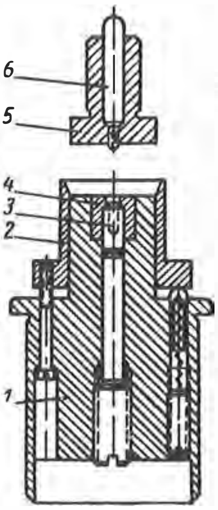


FIGURE 17. Working parts of the die:

1-body; 2-guide; 3-stop; 4-die plate; 5-pressing punch; 6-staking punch.

Figure 17 shows the punches and die for fitting and staking the center wheel of "Pobeda" wristwatches.

If the fitting diameter of the pinion or staff is very small, the wheel is first firmly mounted on a hub (Figure 18), and the hubbed wheel is then mounted on the staff or pinion. After the wheel has been fitted on the pinion, it is aligned in the face plane on the P-32 instrument (Figure 19). The wheel (1) to be inspected is clamped between the centers (2), and is rotated by a driver. Face run-out is noted on the scale of the built-in dial gage (3). The wheel is aligned by hammer (4). The dial gage and hammer are set near the wheel rim.

The driver together with the pulley is driven by the electric motor through a belt transmission. Wheels and balances with diameters between 4 and 15 mm can be aligned on the P-32 instrument. The dial-gage scale has divisions of 0.01 mm. The wheel revolves at 120 rpm and the electric motor at 1500 rpm. The production rate is 1500 subassemblies per shift.

Radial run-out wheels is inspected using either a comparator or a special dial gage (Figure 20).

The instrument consists of a bed (1), a gear pair (2) with handle (3), a driver disk (4), a pair of fixed centers (5), and a dial gage (6) mounted in an adjustable bracket (7). Parts and subassemblies are inspected between male or female centers. Small parts are rotated manually.

Each escape-wheel subassembly is inspected for external diameter run-out and pitch accuracy, simultaneously, on a profile projector at a magnification of 100X, with the aid of the attachment shown in Figure 21. The escape-wheel subassembly (1) is placed in the standard watch movement (2), using pincers. The upper jewel is mounted in a movable clamp (3) which fits into a special cutout made in the standard movement.

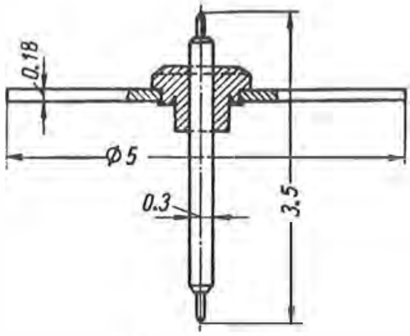


FIGURE 18. Wheel-hub subassembly

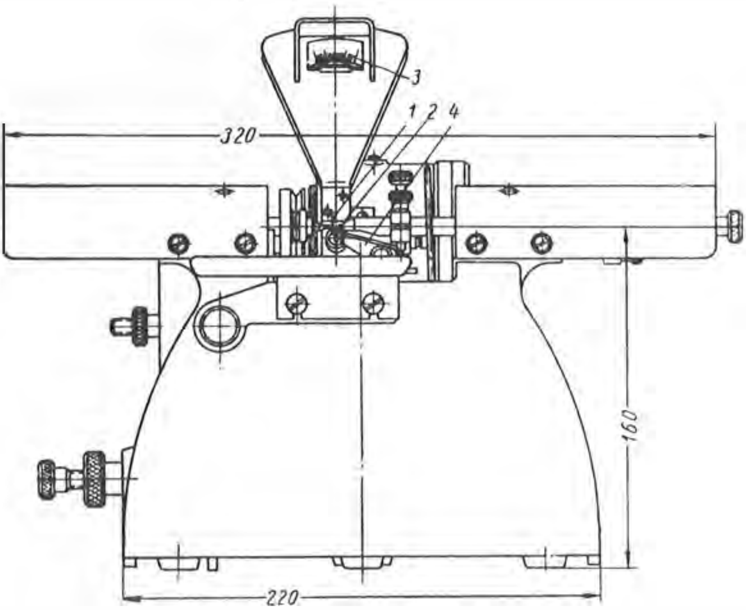


FIGURE 19. P-32 instrument for aligning and for checking the face run-out on sub-assembled wheels and balances

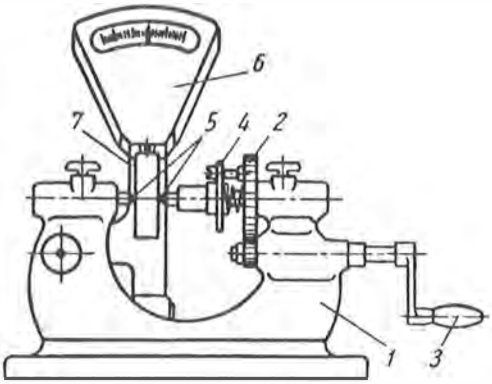


FIGURE 20. Instrument for radial-run-out inspection of wheels

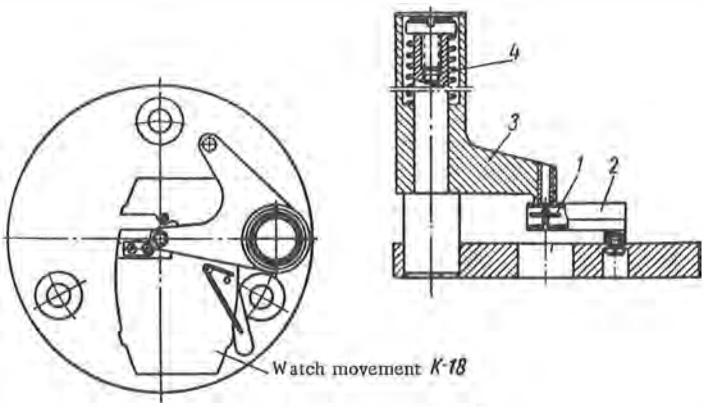


FIGURE 21. Profile-projector attachment for measuring radial run-out and pitch accuracy of escape wheels

TABLE 2

Wheel-assembly testing moments

Subassembly	Testing moments for K-26 watches, g. mm	Testing moments for K-36 watches, g. mm
Center wheel	1650	2500
Third wheel	470	800
Fourth wheel	390	800
Escape wheel	150	600

The subassembly is loaded and unloaded by lifting the clamp (3), thus compressing spring (4). The attachment is mounted on the projector table in such a way that the position of the wheel tooth on one of the pallets of the standard-movement pallet lever is shown on the screen.

A scaled drawing on tracing paper or glass, with lines which indicate the permissible limits of the wheel-tooth radius and impulse-face length, is placed on the screen.

Tightness of the assembly of wheels on pinions is checked by random inspection on the device described below. The pinion is clamped in the collet of the device used, and a moment-creating weight is suspended from the wheel (see Table 2). The assembly is considered satisfactory if the wheel on the pinion does not slip under the weight.

Barrel Assembly

The barrel assembly consists of the barrel body itself (Figure 22, a), the cap (Figure 22, b) the arbor (Figure 22, c), and the mainspring with brace (Figure 22, d). The mainspring is supplied to the watch plant in a finished state. The radial and face run-out of the assembled barrel must lie within specified limits. The maximum permissible radial run-out for the gear rim of the "Pobeda" wristwatch barrel is 0.015 mm. The maximum permissible face run-out on the rim circumference is 0.02 mm. These requirements are very strict, if we take into account that the tightened spring causes the arbor to make full use of any radial clearance of the arbor in the barrel. In order to satisfy such requirements, the radial clearance of the arbor in the barrel must not be more than 0.005 to 0.010 mm, which is achieved by boring the holes in the barrel and cap on the S-79 copy-boring machine.

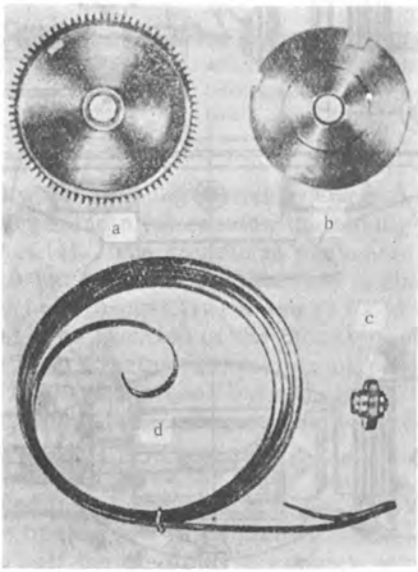


FIGURE 22. Barrel subassembly:

a–barrel body; b–cap; c–arbor; d–mainspring.

Before the holes are bored, the cap is pressed into the barrel body on the D-246 press. Slip is avoided by providing a negative allowance between cap and barrel (0.02 to 0.03 mm for the barrels of the "Pobeda" and "Zvezda" wristwatches and 0.04 to 0.05 mm for the "Molniya" pocket-watch barrels). The barrel height must be held accurately during the pressing operation (Figure 23), and is inspected by means of a vertical dial gage or micrometer.

The holes are bored and the bosses faced (Figure 24) on the S-79 machine, which copies the arbor dimensions.

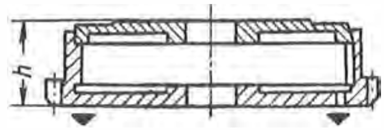


FIGURE 23. Barrel body with pressed-in cap

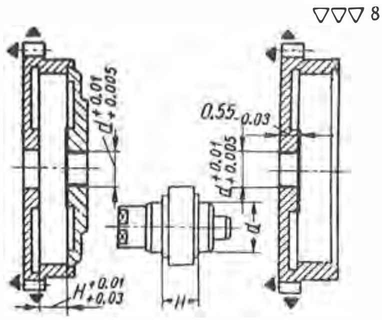


FIGURE 24. Boring holes and facing bosses in the barrel body and cap according to the arbor dimensions

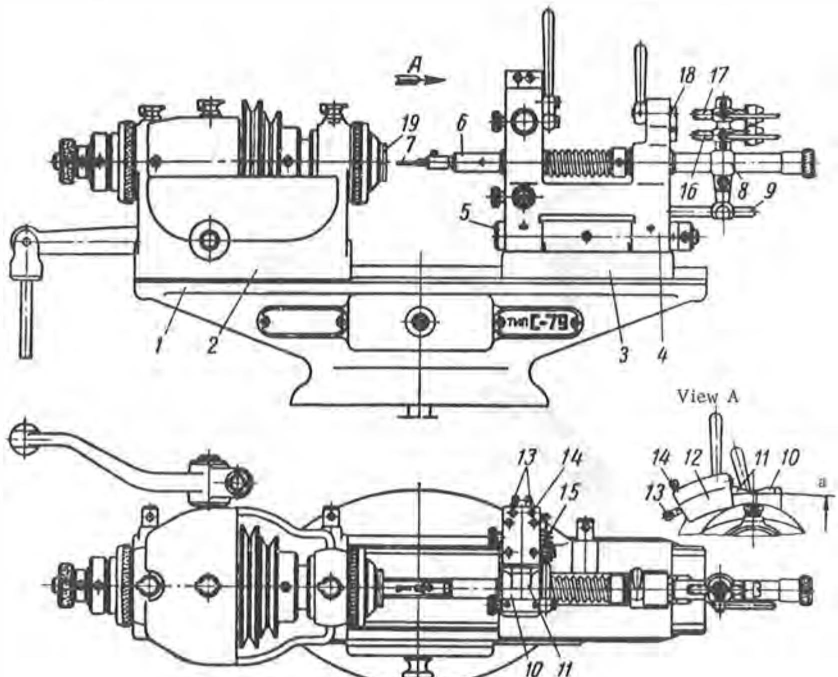
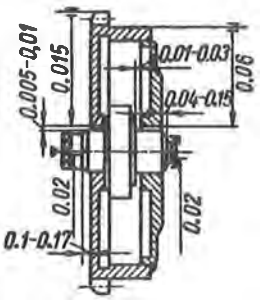


FIGURE 25. S-79 copy-boring machine

The S-79 machine (Figure 25) operates as follows. Headstock (2) is mounted on bed (1). The barrel with cap is clamped in the collet (19) in the headstock spindle.

MMiP U.S.S.R.	Plant	Inspection chart			
Symbol	Subassembly name	For assembly	Category 5	Shop	
K-26-UZ 18	Barrel and cap with arbor	—	5	—	

Name of operation: Inspection of clearances and tightness of cap fit. Drawing of the part to be inspected	Inspected parameter (dimensions and tolerance)	Inspection means: Name	Inspection means: Scale divisions and measurement limits	Drawing number of device	Size of sample inspected, %
	1) Clearances: 0.01—0.03 0.005—0.010	Instrument for clearance measurement. Special center leg	0.001 mm ± 0.03 mm — —	MS —3415 T-3745/54 T-3802/11	100
	2) Radial runout	Special instrument	0.001 mm ± 0.03 mm		100
	3) Tightness of cap fit	Instrument for inspecting the cap fit tightness		MS-3636	5—7
	4) External inspection	Magnifying glass	2.5 ×		100
	5) Dimensions: 0.04—0.15 0.10—0.17	Dial gage with additional table with hole	0.01 mm 10 mm		5—7

A special slide (3) which carries a rocker bracket (4) hinged on axis (5) is mounted on the bed. Spindle (6) carries the boring tool (7) and slides in two bearings in bracket (4). The spindle is prevented from rotating by arm (8) and pin (9). A hardened steel plate (10) is fixed to the top of bracket (4). Two blocks (11), held in post (12) which is fixed to the slide, contact the plate on their faces. The position of the blocks is adjusted by screws (13) and locked by screws (14). Spring (15) maintains contact between the plate (10) and the blocks (11). The distance between the axis of spindle (6) and the axis of hinge (5) is equal to the distance between the axis of spindle (6) and platform a.

The radial clearances [between the arbor and the barrel holes] are established by means of the blocks (11): the blocks are positioned so that the cutting edge of the boring tool is displaced to the left of the spindle axis by a distance equal to half the diameter clearance when the block contacts plate (10). The barrel is fastened in collet (19), the machine is started and an arbor is positioned between one of the blocks (11) and plate (10). This displaces the plate to the left by a distance equal to the arbor diameter. Since the tool spindle is at the bracket half point, the tool is displaced by a distance equal to half the arbor diameter.

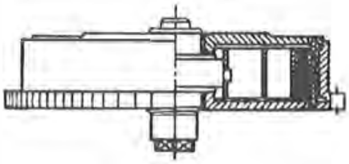


FIGURE 26. Assembled barrel

A hole bored by this method has a diameter equal to the sum of the arbor diameter and the preset clearance. The clearance between arbor and hole is therefore a fixed quantity.

A constant axial clearance between barrel, cap and arbor is also achieved by copying the arbor dimensions. When stop (16) contacts plate (18), the tool faces the inside boss of the barrel body (Figure 24). When an arbor is inserted between plate (18) and stop (17) (Figure 25), the tool faces the inside boss on the cap (Figure 24).

After these operations, the barrel, cap and arbor are assembled and the dimensions of the assembled barrel as well as the tightness of the cap fit are inspected (see inspection chart for "Pobeda" wristwatch barrels).

The barrel is then dismantled and the parts washed and dried.

Finally, the spring is inserted into the barrel body and its outer extremity is fastened to the barrel. The arbor is then inserted and the inner extremity of the spring is fastened to it. The spring is wound one or two barrel revolutions to check the reliability of its fastening and, finally, spring and arbor are lubricated, and the cap is assembled (Figure 26).

Pallet-lever Assembly

The pallet-lever subassembly consists of the lever (1), the staff (2), the guard pin (3), the receiving pallet (4), and the discharging pallet (5) (Figure 27).

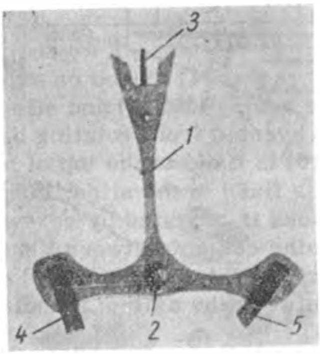


FIGURE 27. Pallet subassembly:

1–lever; 2–staff; 3–guard pin; 4–receiving pallet; 5–discharging pallet.

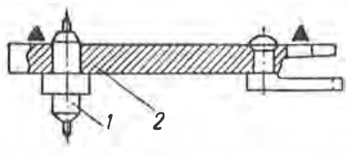


FIGURE 28. Fastening the staff and guard pin to the pallet lever

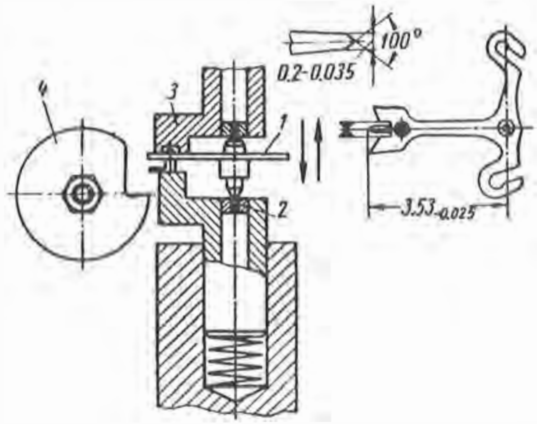


FIGURE 29. Fixture for pointing guard-pin end

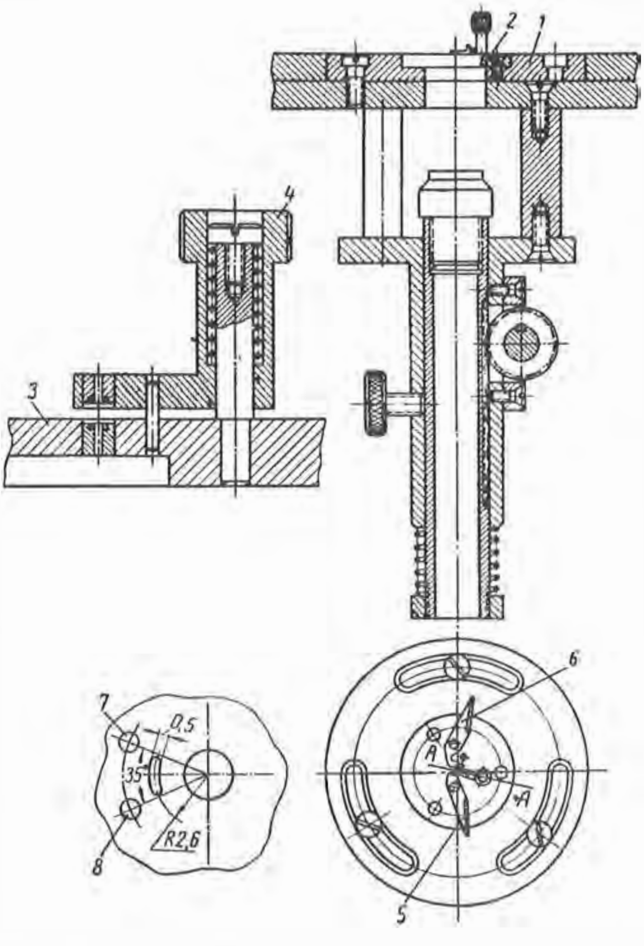


FIGURE 30. Attachment on profile projector for mounting the pallets in the pallet lever

Assembly begins with the pressing-in and the riveting of the guard pin in the pallet lever, using a hand press or the pedal-operated D-246 press (Figure 28).

The guard pin is then set manually, by means of pincers, both with respect to paralelleity to the lever plane and relative to the center line of the fork slot. The guard-pin extremity must not deviate from the center line of the slot by more than ±0.03 mm. The reliability of the guard-pin mounting is checked by random sampling in a special inspection device.

Next, staff (1) is pressed into pallet lever (2) on a hand press or on the pedal-operated D-246 press. The reliability of the mounting is inspected (5% sample) in a special device.

The guard-pin tip is then pointed using a bench-type hand press and a special fixture (Figure 29). The pallet lever (1) is located by its staff journals in the steel bearings (2), and clamped between the plunger (3) and its spring-loaded counterpart. A profiled circular cutter (4), ground to the desired shape of the guard-pin tip, is also mounted on the press. When the plunger, together with the pallet, is lowered, the cutter planes or shaves the pin tip.

Guard-pin pointing is followed by the preliminary setting (in the device) of the pallets in the pallet-lever slots. Their exact setting is performed in a profile projector, on whose table (1) the attachment (2) is mounted (Figure 30).

The attachment consists of a lower plate (3), an upper clamp (4), levers (5) and (6), and setting pins (7) and (8). A drawing of the pallet lever and banking pins on tracing paper or glass is fastened to the projector screen. The pallet lever is mounted in the jewel bearings of the lower plate (3) and the upper clamp (4), and is pressed by pincers against one of the banking pins. The pallet position is projected on the screen through the central hole of the plate and compared with the drawing, on which the limits of the pallet position are marked out. The pallet is displaced along its slot by levers (5) and (6). This method of positioning and inspecting the pallets is very accurate and quick. The pallets are now fixed in position in their slots by molten shellac which flows into the free space in the slots, the lever being heated to 70–80°C on a special brass plate.

Assembly of the Balance

The balance subassembly includes the balance wheel with screws, the balance staff, and the double roller with impulse pin (Figure 31). The balance subassembly must be poised, its screws must be tightly screwed into the wheel, and the double roller and wheel must be reliably fastened to the staff. The assembly operations are as follows: mounting the screws on the balance wheel using adjusting washers under the four compensating screws (Figure 32, a), mounting the balance wheel on the staff and staking (Figure 32, b), setting the balance wheel in the face plane (Figure 32, c), mounting the double roller on the staff (Figure 32, d), and static poising (balancing) of the subassembly (Figure 32, e).

A mechanical screwdriver is used in certain watch plants for mounting the screws on the balance wheel. Its use much simplifies the performance of this complex operation, and increases the production rate for the operation by about 50 %.

The mechanical screwdriver consists of the screwdriver proper, a DT-75 electric motor (n = 2800 rpm) with a flexible shaft, and an RVN-20 vacuum pump with a common air duct for 15 to 20 mechanical screwdrivers (Figure 33).

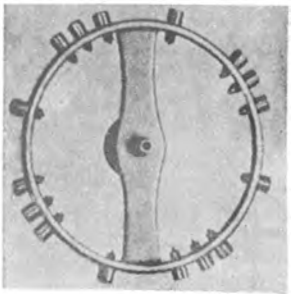


FIGURE 31. Balance subassembly

An aluminum body encloses the screwdriver mechanism and the total weight is less than 150 g. The body is easily dismantled for cleaning. The screwdriver guide shaft (1) is connected at one end to the flexible shaft at the electric motor, and at the other end to the collet holder (3) and collet (4) through the friction coupling (2). When operation is to begin, the motor and pump are switched on, the screwdriver is gripped by the right hand so that the thumb is on the trigger (5) and the balance is held on the table by the left hand. The collet nose is brought near the head of one of the screws, which are spread on an inclined table, and the collet is opened by pressing on the trigger. The screw head is sucked into the collet housing and the trigger is then released. The screwdriver collet nose and the screw rotating with the collet are brought opposite one of the holes in the wheel and the screw is screwed in it. Pressure on the trigger opens the collet and the screwdriver is withdrawn. The entire operation takes a fraction of a second.

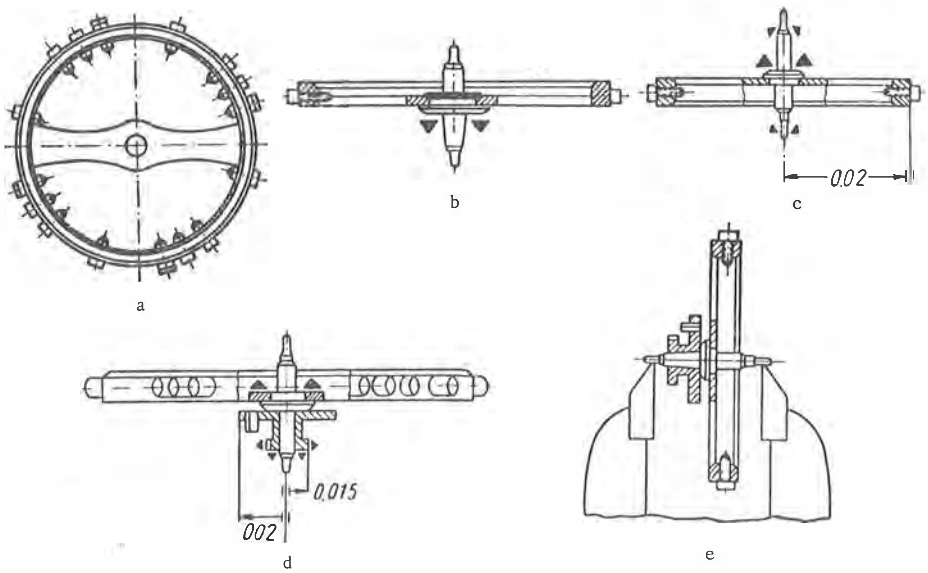


FIGURE 32. Balance assembly:

a–mounting the screws; b–mounting the balance wheel on the staff; c–setting the balance wheel in the face plane; d–mounting the double roller on the staff; e–static poising.

Valve (6) has been provided for cases where defective screws (with a tight thread or none at all) are in the collet, and have to be removed. The spindle nose is inserted into the valve cone (7) and pressure on the valve brings it opposite the hole in tube (8). The vacuum in the tube sucks the screw out of the collet housing (the collet being open) and it falls into the valve pocket. Spring (9) then returns the valve to its initial position.

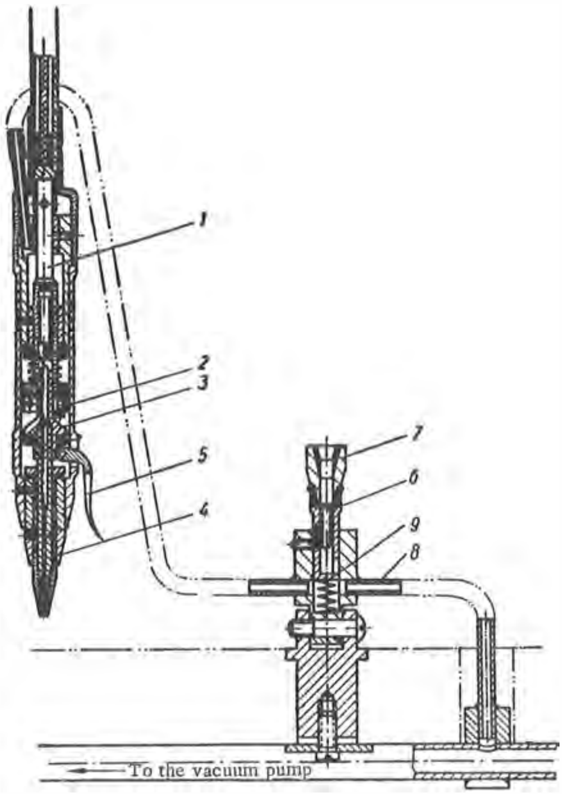


FIGURE 33. Mechanical screwdriver for mounting screws on balance wheels

An automatic machine for mounting screws on the balance wheel of "Zvezda" watches is in use at the Penza watch plant (Figures 34 and 35).

A turret head on this machine has 10 balance housings in which the balances are held by springs. The turret head is imparted a reciprocated motion in a longitudinal direction by a cam. It is indexed 36° each time it is withdrawn, so that one screw is mounted in each of the 10 balances. After one complete revolution of the turret head, the shafts on which the balance wheels are mounted are indexed by an angle which depends on the balance design. In the case of the "Zvezda" balances, which have 12 screws regularly distributed on the wheel circumference, the indexing angle is 30°. All the balances are indexed by the same angle and the mounting cycle is repeated. The machine stops automatically after all the screws have been mounted.

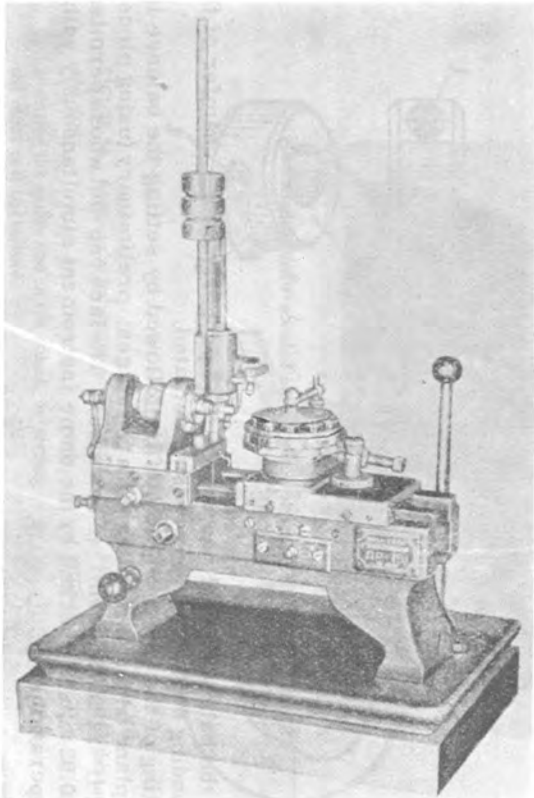


FIGURE 34. PR-151 automatic machine for mounting screws on the balance wheel

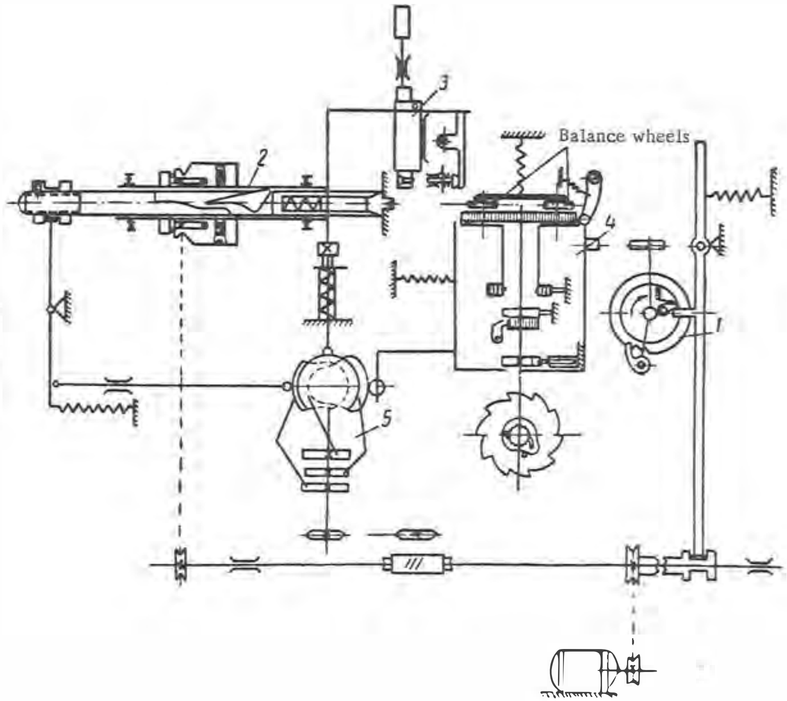


FIGURE 35. Kinematic diagram of the PR-151 automatic machine

The magazine must accurately position the screw relative to the machine spindle collet. The turret head, in turn, must accurately center the balance hole with respect to the screw in the collet.

The magazine (3), is displaced vertically between guideposts by means of a lever and cam (see Figure 35). It is lowered when the turret head is withdrawn, and the casette with the screw is fed to the collet. It is lifted when the turret head approaches, making it possible for the collet to rotate the screw. Spindle (2) has a friction coupling which prevents breakage of the screw in cases of tight threads. The camshaft (5) mounts cams which control the motions of the turret head, the magazine mechanism, and the closing of the collet. The machine handles 10 balances in 2 minutes. Screws are placed in the casette manually, and each screw thread is inspected during loading. The machine is driven by an electric motor. After the screws have been assembled, the balance is directed to the electroplating shops for gold-plating.

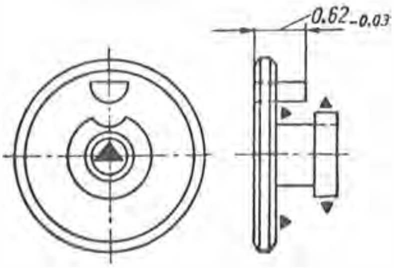


FIGURE 36. Double roller with impulse pin

The balance wheel is mounted on its staff in the same way as wheels are mounted on pinions (D-246 pedal-operated press). The balance staff is inserted into the housing of the lower die with its shoulder serving as supporting surface.

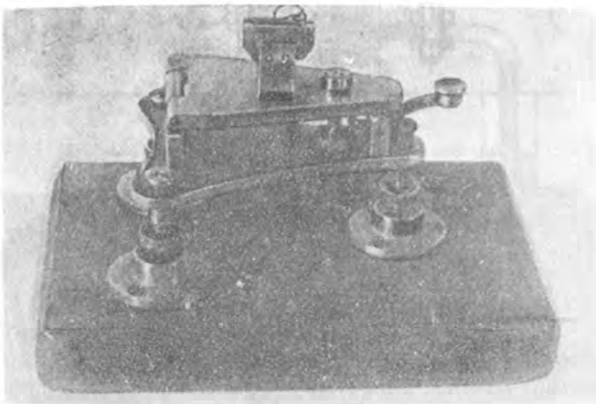


FIGURE 37. Device for static posing of the balance-wheel subassembly

After the balance wheel has been placed properly on the chamfer of the corresponding shoulder, the press is actuated.

Mounting of the wheel on the staff is followed by setting the balance in the face plane which is performed in two stages: preliminary (using pincers), and final (P-32 instrument) (Figure 19). The face run-out whose permissible value is 0.02 mm is checked by the same instrument simultaneously with the setting operations.

The double roller, with the impulse pin previously pressed into it (Figure 36), is set on the staff on a D-246 pedal-operated press. Shellack is melted into the joint after the pin is pressed into the double roller in order to increase the tightness of the assembly. The position of the impulse pin relative to the recess and the central hole of the roller is inspected in a profile projector, and the tightness of its mounting is checked in a special device.

The balance wheel is positioned, using pincers, in a die in the lower shoe of the press. The roller is positioned, again using pincers, on the balance staff and is pushed against the shoulder of the balance staff by means of a punch mounted in the press spindle (see Figure 32, d).

The run-out of the safety (guard) surface (0.015 mm allowable) is inspected using a dial gage (see Figure 20).

The unbalance in the balance wheel, due to inaccuracies in the manufacture of parts and in their assembly, is, to a certain extent, corrected by statically "poising" the subassembly (Figure 37). The balance-staff journals are placed on knife edges made of ruby (see Figure 32, e) and an oscillating motion is manually imparted to the wheel. If the unbalance of the wheel is considerable, it will stop rapidly with the heavy part coming to rest at the bottom. The balance is then removed from the knife edges, and the weight of the screws in the heavier part is reduced (or the weight of the screws on the opposite side increased) by removing or adding adjusting washers. The operation is then repeated, until the balance wheel is clearly in the indifferent state of equilibrium. Static poising is followed by fitting the hairspring, and by dynamic balancing in the P-12 instrument.

Assembly of the Hairspring and Collet

A properly stabilized hairspring has the shape of an Archimedean spiral. The inside end of the hairspring (2) is fastened to a brass bushing (1) (Figure 38, a), called the collet. Pincers are used to introduce the end of the

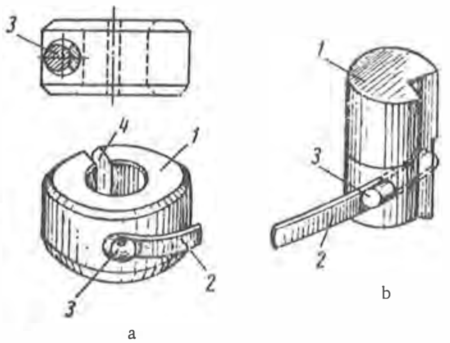


FIGURE 38. Setting the hairspring in the collet and stud:

a–setting the inside end in the collet; b–setting the outer coil in the stud.

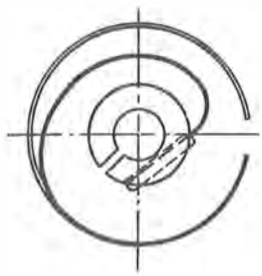


FIGURE 39. Shape of the inner terminal curve

hairspring into the lateral hole in the collet and it is locked in place by the tapered pin (3). The hairspring is aligned (in the plane) and its terminal curve is simultaneously bent. The inner terminal curve is so made that its initial part does not come in contact with the collet when the hairspring is twisted 330°, while, at the same time, its distance from the collet does not exceed a value equal to the spiral pitch (Figure 39).

The outer end of the hairspring is fixed to the stud.

Assembly of the Balance and Hairspring

The assembly of the balance–hairspring system involves mounting the hairspring with collet on the balance staff, establishing the system period, fastening the outer end of the hairspring to the stud, shaping the outer terminal curve, and dynamically balancing the entire system.

The D-246 press, which was used for the double roller, is also used for mounting the hairspring and collet on the balance staff (Figure 40, a and b). Hairspring and balance are simultaneously aligned in the face plane.

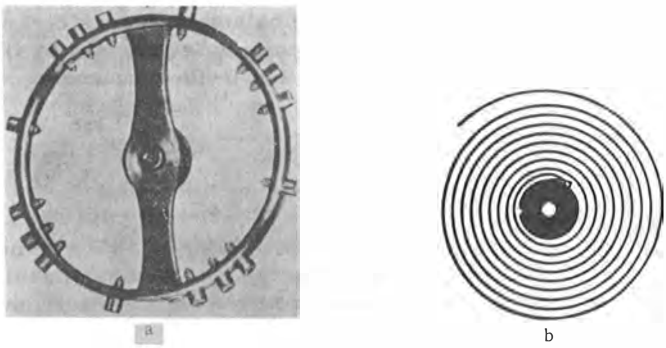


FIGURE 40. Balance–hairspring assembly:
a–balance with staff and double roller; b–hairspring with collet.

The oscillation period of the system is established by the P-12 instrument (see the section on "Watch adjustment"). The period of oscillations is marked on diagram paper and compared with the standard period for the instrument. The period of the system being tested is adjusted by varying the hairspring length (the hairspring has a reserve of 1.5 to 2 outer turns), until it coincides with that of the standard. The system is vibrated in a horizontal position.

After the hairspring has been brought to size, the outer end of the hairspring is fastened to the stud in the same P-12 instrument (see Figure 38,b). The end (2) of the hairspring is introduced into the hole in stud (1) and is fastened to it by the tapered pin (3).

Devices which do not require removal of the hairspring from the balance staff are used to shape the outer terminal curve. The shaping is performed in two steps. A knee bend is first made which raises part of the coil above the hairspring plane, and the terminal curve is then formed according to the shape required.

The inner and outer terminal curves of the hairspring are necessary in order to bring the center of gravity of the hairspring as close as possible to the axis of revolution of the balance wheel.

After the hairspring has been fitted on the balance, the system is dynamically poised, the center of gravity of the entire system is made to lie on the axis of revolution of the balance wheel. The poising operation is performed in the P-12 instrument where the balance-hairspring system operates in a reference watch movement. The unbalance of the system is checked in four vertical positions. Correction is made by removing or adding adjusting washers under the balance screws. Static poising brings the daily (24 hour) error of the system down to 3 to 5 min, and dynamic poising in the P-12 instrument reduces the error to something of the order of 5 seconds*.

WATCH ASSEMBLY

Wrist- and pocket-watches are assembled from as many as 140 to 150 parts parts. Subassemblies are assembled in the mechanical shops in which the parts are manufactured. This closed-cycle organization of the production process has several advantages: simpler production control, elimination of repeated inspection operations, increased responsibility of the mechanical shops for product quality, etc. The assembly shop performs the basic assembly operations, and also the preliminary assembly of separate subassemblies: screwing the dial-leg screws into the plate, fastening the balance cap (with jewel) on the balance cock and mounting the regulator, mounting the keyless wheel and click, etc. As these preliminary operations do not require much work (man-hours), it is not expedient to include them in the cycle of basic assembly operations.

The hand-setting movement is also assembled in an operation which is not included in the cycle of basic assembly operations. The assembled unit is washed after this operation.

In all Soviet watch plants, the basic assembly operations are performed using the conveyor-belt system. The method of team-system assembly for separate assembly operations, formerly used, has been replaced by a new and more advanced method using a closed conveyor-line assembly cycle with fixed rate. Assembly by the earlier method included 7 operations performed by highly qualified specialists. Assembly on an intermittent conveyor line includes 11 to 12 operations requiring assemblers of only average qualifications. Some of the operations relating to the escapement and balance subassemblies are performed outside the conveyor line.

The idea of conveyor-line assembly is not new. It was used for alarm-clock assembly as far back as 1930 in the second Moskva watch plant. Movements being assembled were transferred from one workplace to the next by conveyor belts.

In 1948 the same plant applied the conveyor system to the assembly of pocket watches. A new type of conveyor line, called an intermittent

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* Poising is treated in more detail in the section "Watch adjustment".

conveyor line by its designers, was developed in 1950 at the Penza watch plant. This conveyor line moves intermittently (whence its name) with a definite rate (frequency) adjusted from the foreman's control panel in the course of the workday.

Intermittent-conveyor-line design. The conveyor consists of a row of wood panels (100×80 mm), every second panel carrying work holders on which the watch plates are mounted (Figure 41). The table carrying the belt is so designed as to ensure a more comfortable position for the assembler. The work holders are disposed in such a way that the assembler can work either on the left-hand or on the right-hand holder. This arrangement allows the assembler to conclude an operation when the work is on his right-hand side if he was not able to conclude it while it was at his left. This feature is also necessary for certain complex operations which are performed during two dwell periods. One workplace is assigned for every four work holders, on one side of the conveyor bench.

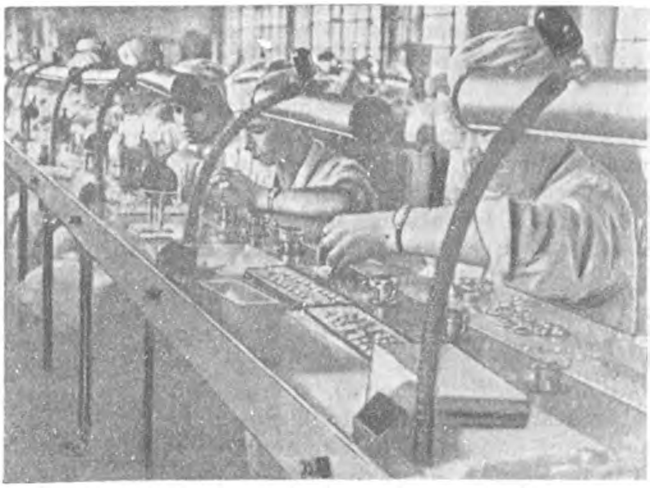


FIGURE 41. Intermittent conveyor line for the assembly of pocket- and wristwatches

The holder on which the watch plates are mounted consists of a body (fastened to the wood panel by its base), a ball-and-socket joint, a fork and a frame. The plate is mounted in the frame so that parts can be installed on it from both sides. If the fork is lifted, one can rotate the frame with the plate by 180° in the fork hinges, after which the fork can be lowered again. The frame is locked by pins mounted on the work-holder body (Figure 42). The raised fork can rotate in the horizontal and vertical planes because of the ball-and-socket joint. The assembler, by rotating the frame with the movement to be assembled in the vertical plane, can conveniently operate on it or inspect it. The frame is provided with additional holes and pins used for fastening assembly fixtures such as a press for hand fitting.

Conveyor-line work planning. Conveyor-line assembly is split into operations requiring the same amount of time, called the dwell time. An operation requiring more time is entrusted to two assemblers. The work-holder bodies are accordingly given alternating colors. The dwell time in the assembly of "Zvezda" watches in the Penza watch plant is 1.5 minutes on the average, being 1.75 min at the beginning and the end of the workday. The conveyor-belt speed is controlled from the control panel. Two breaks of 10 min each are introduced in order to reduce fatigue.

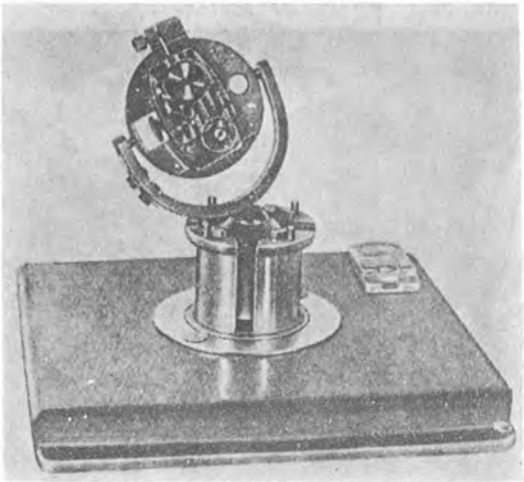


FIGURE 42. Work holder for conveyor-line watch assembly

Three signal lamps are located at each workplace. A green light shows during the work period, a red light during the belt motion, and a violet light during the 10 sec preceding belt movement. Certain plants use a red light only (Figure 43). The assembler's workplace is illuminated by the general lighting system and there is additional local illumination using fluorescent lamps. Fluorescent light has the advantage of reduced reflections from the shining surfaces which most watch parts have and the operator's eyes are less fatigued. The main shortcoming of fluorescent light is a certain flicker which is undesirable for accurate work. Every workplace is provided with a push button for calling the foreman. When the button is pressed, a lamp lights on the foreman's control panel, indicating the corresponding workplace. After the end of each operation the watch movements being assembled are covered by a dustproof plexiglass cap. When the workday is finished, the conveyor belt with the movements is covered by tin hoods and sealed.

Before the assembly begins, the plate with the previously assembled hand-setting movement is fastened rigidly to the work holder. The watches are then assembled in the following sequence.

First operation

Wheel-train assembly

The center, third, fourth, and escape-wheel subassemblies are set on the plate. The assembler mounts the train (central) bridge with the keyless (winding) wheel already mounted. He first sets, using pincers, the center pinion since it has the longest journal, and then proceeds with the other pinions. The bridge is then screwed onto the plate with two screws using a mechanical screwdriver. The assembler then inspects the axial clearances of each gear pair and the face run-out of the wheels. The magnitude of axial displacement is measured on a dial gage, but a trained assembler can judge it by touch. If the axial clearances are larger than specified, which rarely happens, the jewels are displaced by a hand press mounted on the conveyor bench. Face run-out is inspected visually.

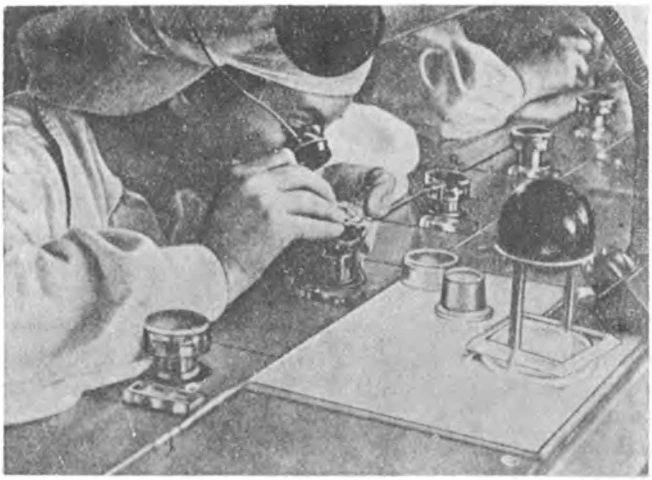


FIGURE 43. Assembler's workplace

After the axial clearances and the face run-out have been inspected, the assembler directs a jet of air at the center wheel, causing it to rotate. Quality of train mesh is assessed from the speed of rotation of the escape wheel and from the noise pattern.

The tolerances on the pinion journal diameters and the jewel holes guarantee the desired radial clearances, and accordingly these are not inspected.

Second operation

Setting the barrel and the barrel ratchet wheel

The assembled barrel is set on the plate and held by a separate bridge on which the click has already been mounted. The assembler inspects the radial and axial clearances, and the quality of the mesh with the center pinion. The barrel ratchet wheel is then set. The barrel ratchet wheel, set on the barrel arbor, must not wobble as this could lead to its coming into contact with the barrel and meshing incorrectly with the keyless wheel and the click. After the subassembly is assembled, the places of contact between the keyless wheel and the cap are lubricated.

The assembler checks the quality of mesh of the whole kinematic chain from barrel to escape wheel in the following manner: by rotating the winding crown, he winds the spring till rotation of the gear wheels sets in. When winding of the mainspring is now stopped, the escape wheel stops for a moment, and then makes several turns in the opposite direction under the reversed action of the spring. The larger the number of these reverse revolutions, the better the mesh or, in the assemblers' language, the easier the "rolling". The number of reverse rotations of the escape wheel in "Zvezda" wristwatches must be not less than 4.

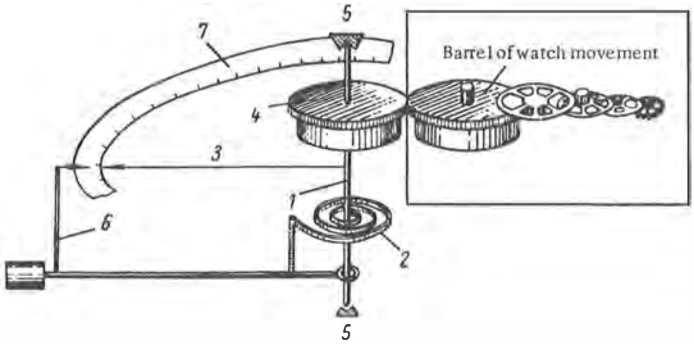


FIGURE 44. Schematic diagram of the instrument for checking quality of mesh

In certain cases the mesh quality is inspected by means of the instrument shown in Figure 44. The driving force of the instrument is supplied by the spiral spring (2) (hairspring). The instrument scale (7) is graduated in g. mm, according to the moment developed by the hairspring, when it is twisted from 0° to 150°. The scale used for wristwatches is graduated from 0 to 15 g. mm. The hairspring (2) and the hand (3) are mounted on axis (1). The second extremity of the hairspring is fastened to the lever (6). The barrel of the watch movement to be inspected is meshed with barrel (4). In the absence of load the hand (3) and the pointer on lever (6) are disposed opposite each other on the scale. Axis (1) rotates in bearings (5).

The instrument hairspring is loaded by rotating lever (6) to the right from its initial position. Hand (3) is set at zero. The hairspring moment, transmitted to the watch movement through barrel (4), increases in proportion with the angle of twist till the transmission being inspected begins to rotate.

At the instant rotation begins the maximum hairspring moment is shown on the scale by the pointer of lever (6). Hand (3) begins to rotate together with barrel (4), and stops when the moment on barrel (4) becomes equal to the friction moment in the train. This moment is calculated as the difference between the readings of the lever indicator (6) and hand (3). This instrument, therefore, determines the friction losses in the wheel train. The starting moment was found to be roughly twice the friction moment.

Third operation

Mounting the pallet lever and inspecting the relative position of the escapement-wheel teeth and of the pallets

The assembler inserts the lower journal of the pallet subassembly into the cap jewel, locks the bridge in position with two pins and, after inserting the upper journal into the bridge jewel, presses the bridge firmly against the plate and tightens the screw. The axial clearances in the jewels are inspected using the same method as was used for the wheels. Radial clearances are not inspected.

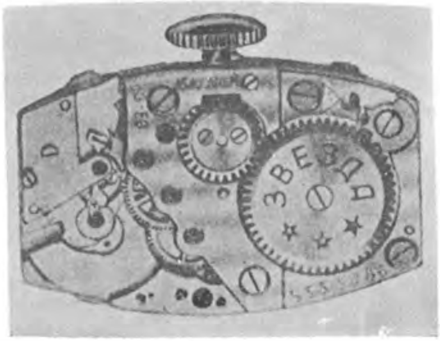


FIGURE 45. "Zvezda" watch movement after the third operation

After the axial clearances have been inspected and any possible skew corrected, the assembler checks the height position of each escape-wheel tooth on the receiving and discharging pallets. The locking, run-to-bankings and drop angles are then inspected visually. To that end, the spring is wound by $1\frac{1}{2}$ to 2 turns of the winding crown, and the pallet fork is displaced from one banking pin to the other using pincers, until the escape wheel has completed one full revolution. If the escape wheel has a large radial run-out, it can happen that the "run-out" tooth on the escape wheel does not free the pallet impulse face, and the watch stops. Conversely, it could happen that the short escape-wheel tooth has a very small locking angle with the pallet which does not ensure the action of the escapement guard devices (guard pin, horns, and double roller with impulse pin).

Apart from the axial clearances, the assembler inspects the clearance between the tooth heel and the pallet back face. The value of this clearance for the discharging pallet (Figure 46) is $1°39'30''$(drop angle) or 0.077 mm. This operation takes twice the time required for the previous operation, and it is therefore performed by two assemblers in parallel at the same time. Figure 45 shows a "Zvezda" watch movement after the third assembly operation.

Fourth Operation

Mounting the lower balance endstone cap and the balance

This operation is preparatory to the fifth operation. The plate is rotated to a dial-side-up position and the place where the cap is to be fitted is cleaned by an air jet. The cap with the jewel is mounted, and the plate is returned to its former position. The balance and hairspring assembly is then set on the plate, the journal is carefully introduced into the lower balance endstone cap jewel and is covered by the balance cock on which the regulator, the upper cap and the stud screw have already been mounted. The assembler adjusts the axial clearance between the balance journals and the jewels by introducing washers between plate and cock, or by bending the cock somewhat, to which end it is provided with a special recess.

Fifth operation

Establishing guard clearances between the pallet fork and the double roller. Removing the balance from the movement

In order to establish the necessary clearance between the escapement guard pin and the double-roller safety surface, the assembler winds the spring until the fork contacts one of the banking pins. Then. using pincers, he draws the fork away from the banking pin until the guard pin comes into contact with the roller safety surface. The magnitude of the clearance is determined from the magnitude of the fork (pallet) deflection from the banking pin. The fork is then displaced to the second banking pin, and the procedure is repeated.

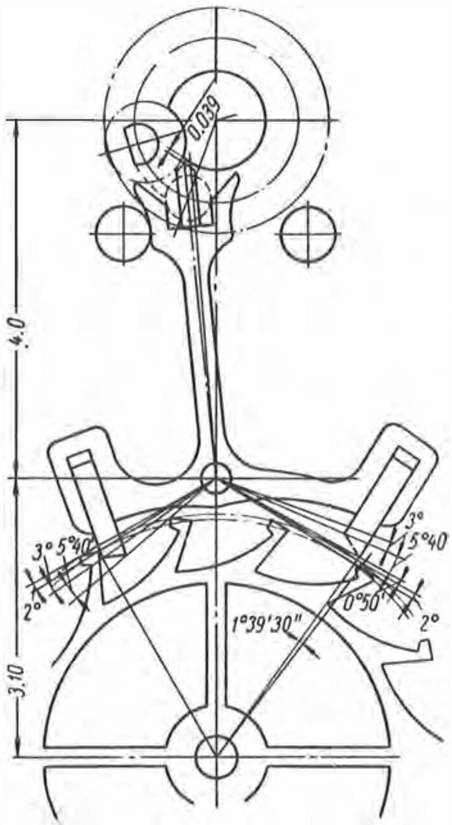


FIGURE 46. Position of the escape-wheel tooth and the receiving pallet during locking

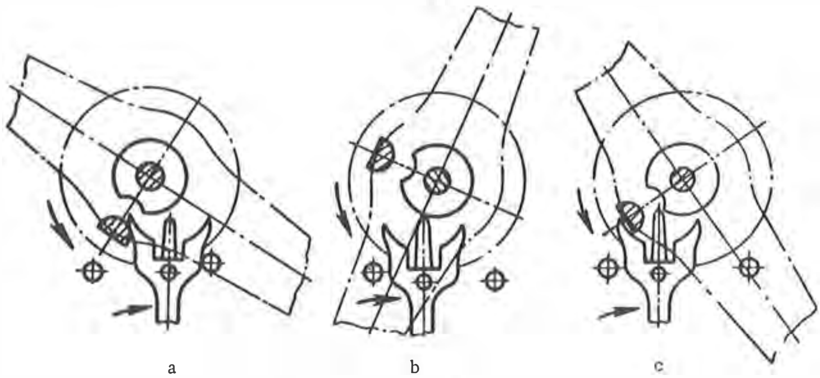
If the clearance is too large or too small, the pallet lever is removed from the movement and the guard pin is shortened or drawn out. After the required clearances have been set, the assembler inspects the clearances between the horns and the impulse pin.

The operation of the escapement will now be described briefly in order to make clear the question of the clearances. The lever escapement (as do all other escapements) performs two functions: it periodically transmits impulses to the balance in order to sustain its oscillations, and it periodically unlocks the wheel train for rotation, as can be seen from the intermittent motion of the seconds hand. The seconds hand is at rest for roughly 0.95 sec, and in motion for the remaining 0.05 sec. Escapements must be designed so that their functioning is not disturbed by sudden external jolts, and they are therefore provided with special guard devices.

The lever escapement of "Pobeda" watches is shown in Figure 46.

When the escape-wheel tooth is on the receiving-pallet locking face, the fork contacts the left-hand banking pin and the balance moves in a free oscillation to the left of the equilibrium position. If the escapement functions properly, that is if there are no sudden jolts, the balance will introduce the impulse pin into the fork notch when it returns to its equilibrium position. On overshooting the equilibrium position, the impulse pin knocks the fork 3° to the right (locking angle). The escape-wheel tooth passes from the locking face of the receiving pallet to its impulse face and rotates the pallet lever by the impulse angle of 7°40' (5°40' pallet angle + 2° tooth angle). The fork notch in turn transmits the impulse to the balance, which moves in a free oscillation to the right of the equilibrium position. Under the action of the drawing force on the discharging pallet, the pallet lever travels an additional angle (0°50'), called the run-to-bankings angle, and reaches the right-hand banking pin.

Assume that the escapement has a short guard pin and that the fork under the influence of a sudden jolt has receded from the left banking pin so that the escape-wheel tooth has passed from the locking face to the impulse face of the receiving pallet. The moment transmitted by this tooth will then rotate the pallet fork through 8°30' (5°40' + 2° + 50') until it engages the right-hand banking pin. The balance, on returning to the equilibrium position, will no longer be able to introduce the impulse pin into the fork notch. The pin will instead strike the outer surface of the fork horn and the balance will stop (Figure 47, a).



a b c

FIGURE 47. Action of the guard devices:

a–premature throw of the pallet-lever fork, guard pin being short; b–guard pin engages the roller (safety surface) preventing fork rotation; c–horn engages the impulse pin.

A blow of this nature usually breaks the impulse pin. In order to prevent watch stoppage and the accidental passage of the pallet fork from one position into the other, a guard pin of suitable length is mounted in the fork, and the balance double roller has a cylindrical guard surface with a recess. When a sudden jolt occurs, the fork leaves the banking pin but the guard pin touches the safety surface and prevents the escape-wheel tooth from slipping onto the impulse face (Figure 47, b). A clearance is specified between the guard pin and the safety surface in order to avoid unnecessary friction during normal functioning of the escapement. The angular value of this clearance must be smaller than the locking angle. The clearance is usually between 0.03 and 0.05 mm (see Figure 46).

In order to make possible the rotation of the pallet fork from one banking pin to the other in normal functioning, a recess for the passage of the guard pin is made in the roller safety surface. The recess is located on the same radius as the impulse pin. It might happen that a sudden jolt occurs at the moment the guard pin has entered the recess (Figure 47, c). Then, the preventive functions pass to one of the fork horns, which will engage the impulse pin and prevent the escape-wheel tooth from passing to the pallet-impulse face. The clearance between the horns and the impulse pin must therefore be smaller than the locking angle.

This clearance, however, must be larger than the clearance between the guard pin and the safety roller. This is specified in order to enable the impulse pin to pass freely past the horn and enter the fork notch when the guard pin contacts the roller safety surface. Friction between the guard pin and the double roller, when they come into contact, must be a minimum, and the contacting surfaces are therefore finished to a class 10 or 11 surface finish.

The guard clearances for the guard pin and the horns are thus fixed as a function of the locking angle.

While setting the guard clearances, the assembler inspects the relative positions of the impulse pin, the safety surface of the double roller, the guard pin and the fork horns in the vertical plane (Figure 48). After the escapement has been adjusted, the balance is removed from the movement. The operation is performed in parallel by two assemblers.

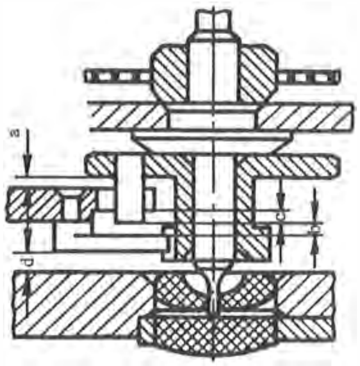


FIGURE 48. Vertical clearances:

a–between fork and double roller; b–guard pin and impulse pin; c–horns and impulse pin; d–guard pin and plate.

Sixth operation

Lubricating the watches

The parts which are lubricated are the balance-staff bearings, the train axes, and the pallets. The pallet-staff jewels are not lubricated, but the staff itself is rubbed with oil. Only well-cleaned surfaces should be lubricated.

Oil is introduced into the watch movement by means of an oil dispenser (Figure 49, a). It is made of stainless steel with tips of different shapes and dimensions (Figure 49, b). Oil is stored at the workplaces in closed oil receptacles (Figure 50).

Lubricating oil reduces and stabilizes friction, reduces (and sometimes prevents) the wear of surfaces in friction, and protects the surfaces from corrosion.

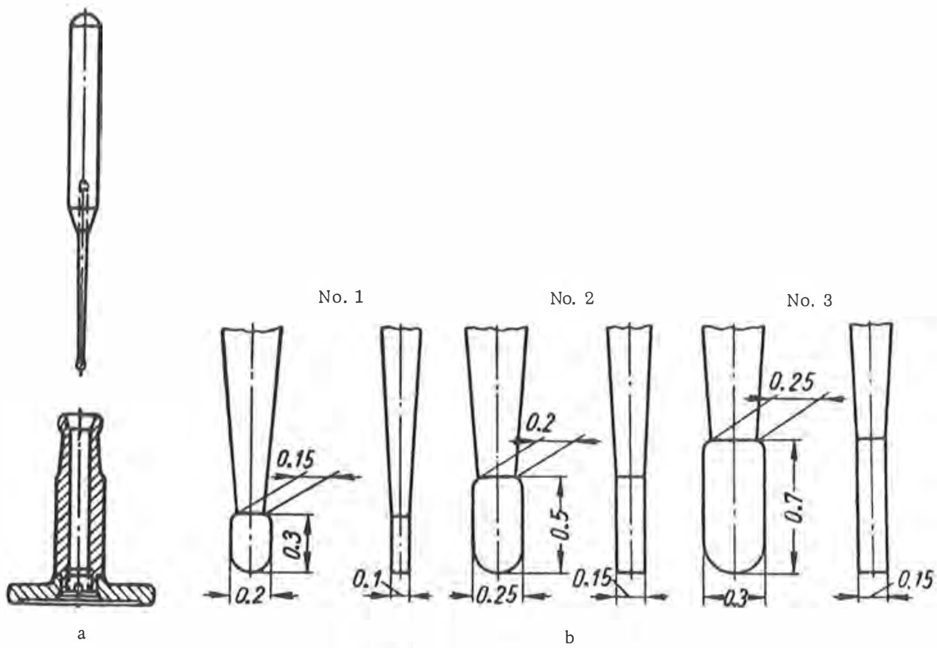


FIGURE 49. Tool for lubricating watch movements:

a–oil dispenser with base; b–tips.

Watches operate for several years without oil replacement. The oil, while at first tending to run, is yet mostly retained in the bearings. However, in the course of time it oxidizes, thickens, and collects mechanical and other kinds of dust. Lubricating oils used in watches must therefore have a high lubricating capacity, chemical and physical stability, and optimum viscosity. Certain grades must also have a wide temperature range of application.

FIGURE 50. Oil receptacle

High lubricating capacity is necessary for the reduction of friction, and thus of wear on the friction surfaces. Mineral, vegetable and animal oils differ in their lubricating capacity. NIIChASPROM investigations established that the coefficient of sliding friction for a steel-glass mating pair is reduced from 0.28, for dry friction, to 0.21 when mineral-oil lubrication is used, and to 0.16 with bone oil. Bone and vegetable oils are, on the other hand, more prone to oxidation than are mineral oils. Watch movements are lubricated using compound oils made up of fractions from the vacuum distillation of mineral and bone oils, and synthetic additives. Various grades of watch oil are manufactured, and the grade to be used in each case is determined by the speed of rotation and the contact pressure of the friction pairs. The grade is determined by the percentage ratio of the basic components and additives, and is characterized by the physicomechanical properties listed in Table 2.

TABLE 2

Physicomechanical properties of watch oils

Oil grade	Use	Acidity number, mg per 1 g of oil, according to GOST 5985-51, maximum	Engler viscosity GOST 33-53		Pour point, °C, GOST 1533-42, maximum
			at 50°C	at 20°C	
MBP-12	Balance and pallet bearings of wrist- and pocket-watches	0.18	2.8—3.2	8.4—9.6	—20
MZP-6	Train bearings of wrist-and pocket-watches	0.18	3.3—3.6	10.9—11.9	—20
MTs-3	Barrel subassembly of wrist-and pocket-watches and alarm-clock bearings	0.18	3.9—4.2	13.3—14.3	—15
PS-4	Alarm-and table-clock springs	0.40	4.5—4.9	—	—
RS-1	Keyless work subassembly	0.8	—	—	—

The amount of oil used in lubrication must be strictly controlled, as an unduly large amount could impair watch operation. Thus, if oil drops are present in the pallet-arbor jewels, an additional moment must be applied in rotating the pallet lever to overcome the liquid friction in the oil layer.

Seventh operation

Movement starting (preliminary)

The assembler sets the balance with the hairspring in the lubricated jewels in the cock and plate, fastens the hairspring stud, inspects the clearances between the balance wheel, the hairspring and the parts lying near them, preliminarily sets the hairspring in the plane and with respect to the center, and establishes the clearance in the regulator curb pins.

Eighth operation

Movement starting (final)

The hairspring is finally and accurately set in the plane and on center. Figure 51, a shows the method of setting the outer terminal curve in the plane by means of pincers, and Figure 51, b shows the curve position after the setting. The plane of the terminal curve is parallel to the lower plane of the balance cock.

Incorrect positioning of the outer terminal curve in the horizontal plane upsets the shape of the whole hairspring, and the turns become irregularly disposed (Figure 52, a and b).

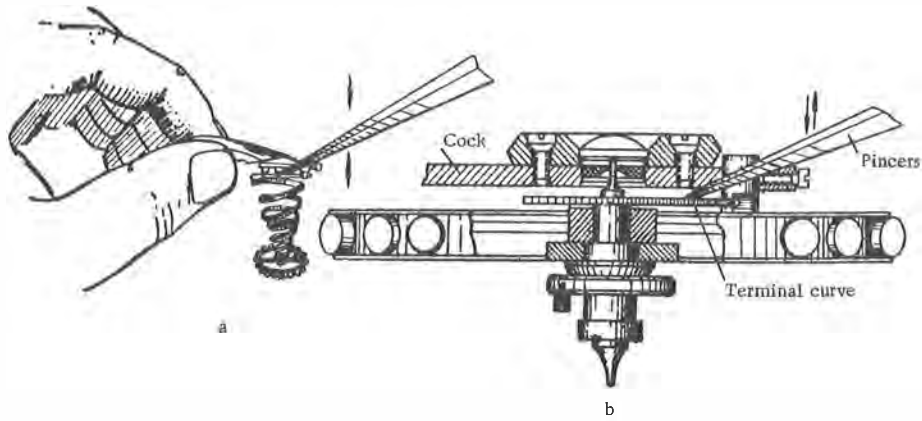


FIGURE 51. Setting the outer terminal curve of the hairspring in the plane

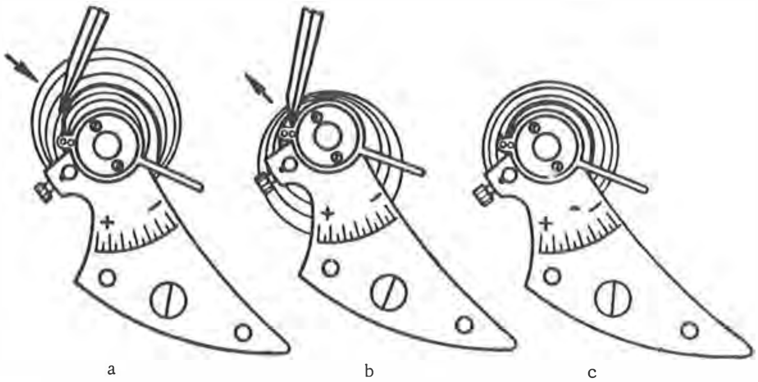


FIGURE 52. Setting the outer terminal curve of the hairspring according to center

The hairspring is returned to its normal shape by manipulating the outer terminal curve, using pincers (Figure 52, c). If necessary, the inner terminal curve is also modified and the assembler then sets the final clearance between the regulator curb pins.

The total clearance between the hairspring and the regulator curb pins (Figure 53) must be between 50% and 100% of the hairspring thickness. By rotating the regulator to its extreme positions, the assembler checks the clearance established and the correct position of this sector of the outer terminal curve; the curve in this sector is then adjusted if necessary.

The assembler now "centers" the escapement. With the mainspring completely unwound, the balance must be so positioned that the impulse pin will lie on the line connecting all centers while being inside the fork notch (Figure 54). The pallet fork must be positioned equidistantly from the two banking pins and must contact the escape-wheel tooth on the impulse face of the receiving or discharging pallet. Only under these conditions will the watch motion be regular. To set the impulse pin on the line of centers in the equilibrium position for the balance and hairspring, the hairspring collet must be rotated on the balance staff. Finally, the assembler starts the movement by winding the mainspring 2 to 3 turns of the winding crown. This must start balance oscillations without any additional mechanical prompting. The ninth operation, being complex and crucial, is performed in parallel by two assemblers.

Figure 55 shows a "Zvezda" watch movement after the eighth operation.

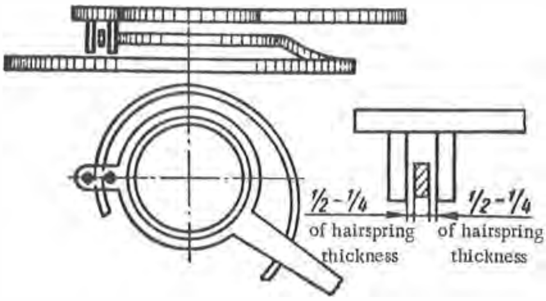


FIGURE 53. Clearance between the terminal curve and the regulator curb pins

FIGURE 54. Centering the escapement and balance

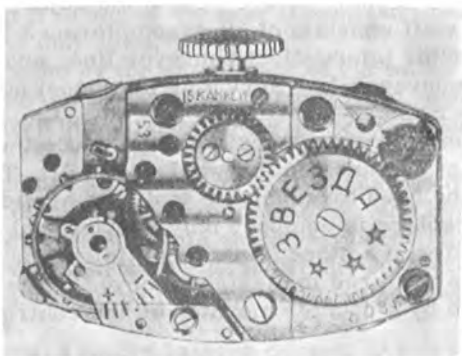


FIGURE 55. "Zvezda" watch movement after the eighth operation

Ninth operation

Mounting the motion work and the dial

The assembler rotates the movement on the work holder from the bridge to the dial side, places the cannon pinion on the center pinion, checks the frictiontight fit of the cannon pinion on the center pinion. He then checks the smoothness of rotation of the cannon pinion, sets the minute wheel, checks the mesh with the cannon pinion, and places the bridge. He then slips the hour wheel onto the cannon pinion and adds a washer to which he gives a spherical shape. The dial is set after the motion work has been assembled. If the dial is to be fastened by screws it is necessary to ensure a uniform clearance in the dial holes between the latter and the hour wheel sleeve and the seconds hand axle, respectively.

Tenth operation

Setting the hour, minute and second hands

The assembler places the hour, minute and second hands, aligns them in the plane and bends the end of the minute hand. The hands must not touch each other or the dial during rotation, must sit tightly on their axles and indicate the time in a coordinated manner.

Eleventh operation

Inserting the movement in the case

The assembler charged with this final operation removes the watch movement from the conveyor work holder and inserts it into the case. He then places the bezel and checks if the minute hand does not touch the crystal.

The watches thus assembled are sent to the adjustment section.

The assembly staff consists of 19 assemblers: 3 for the preparatory operations, 14 for the intermittent conveyor line, and 2 for adjustment and inspection. The conveyor-line servicing personnel consists of a foreman, a material supplier and an inspector.

Intermittent conveyor lines considerably reduce the man-hours required and puts less strict demands on the worker's skill. The general assembly is improved and the need for complete tool sets at each workplace is eliminated. Each workplace is equipped only with the tool for performing a specific operation and with a stock of parts sufficient for the daily production schedule. Parts are stored in plexiglass boxes. The number of assembled watches is counted by a counter mounted on the control pannel.

WATCH ADJUSTMENT

Watch adjustment aims at guaranteeing watch accuracy for a long time and is achieved by varying the moment of inertia of the balance and the length of the hairspring.

The period of free oscillations of the balance is expressed by the formula

$$T = 2\pi \cdot \sqrt{\frac{J}{k}} . \qquad (5)$$

where T = oscillation period of the balance, sec;
J = moment of inertia of the balance, g. mm. sec^2;
k = hairspring moment per radian of rotation, g. mm.

Inserting the value of the moment of inertia of the balance ($J = mr^2$) and the moment of the hairspring $\left(k = \frac{Ebh^3}{12 \cdot L}\right)$ in (5), we obtain

$$T = 4\pi \sqrt{\frac{3 \cdot m \cdot r^2 \cdot L}{E \cdot b \cdot h^3}}, \tag{6}$$

where m = balance mass;
r = radius of gyration of balance;
L = length of hairspring;
b and h = width and thickness of the hairspring cross section, respectively;
E = modulus of elasticity of the hairspring material.

It is seen from (6) that the period of the balance oscillations increases with an increase in the moment of inertia of the balance wheel and with the hairspring length, and decreases with an increase in the modulus of elasticity and the cross-sectional area of the hairspring. The hairspring thickness has the greatest influence on the oscillation period: the period decreases by a factor of $2\sqrt{2}$ when the thickness is increased by a factor of 2; it increases by a factor of only $\sqrt{2}$ when the length is doubled.

As was mentioned earlier, the balance-hairspring system is preliminarily adjusted during its assembly by altering the hairspring length. This operation, called vibration, is performed with the help of the P-12 instrument and a special head.

Before the watches are marketed, they are tested and inspected according to the specifications established by GOST. The maximum permissible daily (24-hour) error for wristwatches is (GOST 6519-53) 30 sec for class A and 45 sec for class B in any of the four testing positions: dial up, crown down, crown up, and dial down.

This test is preceded by the adjustment of the watch in six positions: dial up, dial down, crown up, crown down, crown right, and crown left. Maximum daily error after this adjustment is 20 sec for class A and 30 sec for class B.

The balance period is a function of the balance and hairspring dimensions and the modulus of elasticity of the spring only, and is independent of the amplitude of the oscillations. This quality is called isochronism and is expressed by formula (5) which holds for the case of free damped oscillations, when the balance-hairspring system does not receive oscillation-sustaining impulses.

Influence of impulses on the balance period. An external force acting for a short period of time on the balance-hairspring system changes its oscillation period. The variable force (impulse) transmitted from the mainspring through the lever escapement which acts periodically on the balance constitutes such an external force. Random jolts are another example of period-changing forces.

We will now examine the influence, on the period, of the impulses transmitted from the lever escapement. The balance motion at any moment will be called descending if its direction is from the position of maximum deflection toward the equilibrium position, and ascending if its direction is from the equilibrium position toward the position of maximum deflection.

As was shown above, the escape-wheel tooth is unlocked and the impulse transmission begins before the equilibrium position is reached. Impulse transmission ends after the equilibrium position has been passed.

It was found that the period in a descending motion decreases if the force acts in the direction of motion of the balance, and increases if it acts in the opposite direction.

The unlocking force, acting in the direction opposite the balance motion, therefore increases the oscillation period. This increase will be the smaller, the nearer the unlocking to the equilibrium position. Escapements with a minimum angle of rotation for the pallet lever are to be preferred in this respect.

The period of an ascending motion increases if the force acts in the direction of motion of the balance, and decreases if it acts in the opposite direction.

The impulse transmitted to the balance after the equilibrium position therefore increases the oscillation period. The longer the contact path for the escapement and balance, the greater the influence of the impulse on the period, and therefore the angle of rotation of the escapement must be a minimum. It also follows that the half-periods of the ascending and descending motion are not equal.

Changes in the value of the impulse lead to a variation in the half-periods, and thus in the period of the balance. A constant period of oscillation can be obtained by stabilizing the value of the impulse transmitted.

Special devices, called *impulse stabilizers*, are used in certain watches for this purpose. A constant amplitude (5° maximum variation) is achieved by means of such stabilizers, and the watches operate under steady conditions achieving an accuracy of 1 to 2 sec daily error. The influence of impulse variation on the oscillation period is more pronounced for small amplitudes. In some cases period variations occur without amplitude variation as, for instance, with a nonpoised balance wheel.

In most cases, variations in the balance period are a consequence of amplitude variation and are a result of the fact that the oscillations of the balance interacting with the escapement are not *isochronous*, in other words, the periods of the forced oscillations of the balance depend on their amplitude.

If the watch is adjusted at some mean amplitude, the period will, as a rule, be larger than normal for small amplitudes (140–170°), and less than normal for large amplitudes (280–320°). The watch will lag in the first case, and advance in the second.

The causes of variations in the amplitude, and therefore in the period, are numerous. Some of the most important ones are:

variation of friction in the bearings;

unbalance in parts of the balance subassembly;

different positions of the hairspring between the regulator curb pins and the shape of the terminal curves;

variation in the value of the moment transmitted from the mainspring;

variations in the lubricant properties;

action of magnetic fields;

variations connected with inaccuracies found in the assembly of the wheel train, the escapement, etc.

We will examine the influence, on the accuracy of the watch, of the above-listed factors.

Variation in bearing friction. The largest variations in the amplitude occur in the following two cases: 1) when the watch position is changed from horizontal to vertical; 2) at maximum and minimum spring tension.

The decrease in amplitude accompanying a change from horizontal to vertical position of the watch is due to the increase in the friction moment in the bearings. In the horizontal position (dial up or down) the balance staff rests with its spherical heel on the endstone face and the friction moment is very small because of the very small friction radius. In vertical position of the watch the balance rests with its two staff journals on the cylindrical surface of the jewel bearings. The friction moment is much larger than in the first case because of the much larger friction radius, equal to the journal radius.

In order to reduce the difference between the friction moments at horizontal and vertical positions of the watch, the jewel hole is rounded, using a radius equal to two hole diameters, and a small land is formed on the balance-staff heel. The rounding of the jewel hole also reduces the influence of the oil on the watch movement.

Variation in the moment transmitted. It was mentioned earlier that change in the moment transmitted from the mainspring causes a sharp variation in amplitude. The moment of the mainspring in its middle working range is roughly proportional to the deflection angle. The value of the amplitude for a completely wound spring (4 to 5 turns) and good assembly is 280–320°. It drops to 140–170° when the spring is wound 1 to 1.5 turns. Watches adjusted at 2 to 2.5 turns will therefore advance at the beginning, and lag at the end (after 24 hours). Interference with isochronism is most clearly apparent in this last case. In order to reduce the difference between the two winding extremes, the maximum and minimum moments of the spring are made as near to one another as possible: the maximum difference between them must not exceed 25%.

FIGURE 56. Balance with displaced center of gravity

Pocket-and wristwatch springs are calculated for a minimum of 45 hours watch operation per winding.

Unbalance of the balance-hairspring system, or displacement of the center of gravity relative to the axis of revolution, is one of the main factors producing the so-called position error in watches. This displacement occurs in spite of the high accuracy of manufacture of the balance and hairspring (geometric dimensions), and in spite of the static poising. The displaced center of gravity q (Figure 56) causes an additional moment during balance rotation which influences the watch in a manner which depends on its position. A rule exists for the determination of the position of the center of gravity of the balance:

1. If, when the balance passes through its equilibrium position, its center of gravity is situated below the axis of revolution, the watch will advance at an amplitude of 140 to 170°, and lag at an amplitude of 280 to 320°.

2. If, when the balance passes through its equilibrium position, its center of gravity is situated above the axis of revolution, the watch will advance at an amplitude of 280 to 320°, and lag at an amplitude of 140 to 170°.

If the center of gravity is situated on the horizontal diameter, the watch will not have a position error, as can be seen from the formula

$$\omega = -43\,200 \cdot \frac{P \cdot l}{k} \cdot \cos\beta \cdot S(\Phi), \tag{7}$$

where ω = daily (24-hour) watch error;
P = balance weight;
l = distance between the center of revolution of the balance and its center of gravity q;
k = moment of hairspring when it is wound one radian;
β = angle between a vertical line passing through the balance center and the ray passing through the balance center and its center of gravity;
$S(\Phi)$ = an alternating slowly convergent series arranged according to increasing values of the amplitude.

The function $S(\Phi)$ is shown in Figure 57. The daily error will be zero in the following three cases:

1. for $\beta = 90°$; $\cos\beta = 0$; $\omega = 0$;
2. for $l = 0$ — $\omega = 0$;
3. for $\Phi \approx 220°$; $S(\Phi) = 0$; $\omega = 0$.

The daily error will be smaller, the smaller the balance weight and the higher the hairspring moment. It is seen from Figure 57 that small deviations of the amplitude value from the value at point Φ = 220° cause large changes in the function $S(\Phi)$ and therefore in the daily error. It is therefore more expedient to operate in the amplitude range from 305 to 320°, since a variation in the amplitude over this range has almost no influence on the value of $S(\Phi)$, and therefore on the daily error.

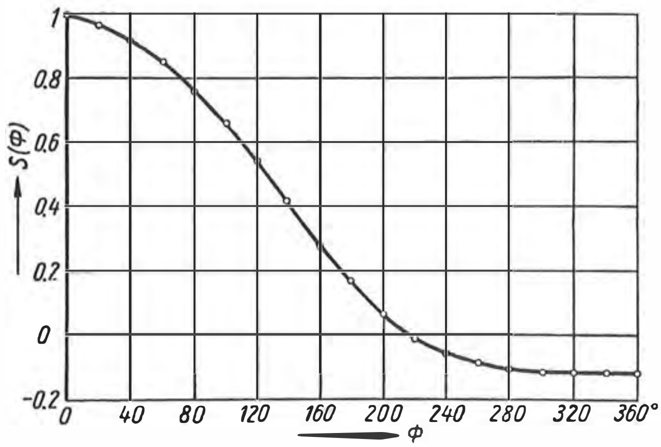


FIGURE 57. The function $S(\Phi)$.

The unbalance of the balance wheel is inspected in the following watch positions: crown up, crown right, crown down, crown left. The influence of the escapement unbalance and clearance fluctuations on the watch error is simultaneously inspected in each of these positions. The adjustment technique in the positions indicated is as follows: the balance screws are arbitrarily numbered as shown in Figure 59, the numbering beginning from the screw opposite the hairspring stud in the equilibrium position of the balance. The spring is wound 1 to 1.5 turns, and an amplitude of 140 to 170° is set. Time indications from the P-12 instrument in each of the positions are recorded and the position of the center of gravity, or the heavy balance sector, is found from the recording. The balance wheel is poised by reducing the weight of the screw in the heavy zone or increasing the weight of the opposite screw. This is done by placing, or removing, adjusting washers located under the screw heads. Dimensions for the washers used in "Zvezda" and "Pobeda" balances are given in Figure 58. Washers of various thickness are available. Two washers 0.01 mm thick will make the watch advance (or lag) 20 sec in 24 hours; 0.02 mm and 0.03 mm thick washers will produce 40 and 60 sec effects respectively, etc.

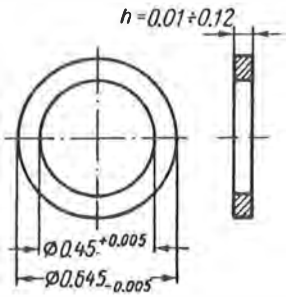


FIGURE 58. Balance-adjusting washers

Example of the adjustment of a "Pobeda" watch.

The following daily errors were recorded in tests on a P-12 instrument:

1. At small amplitudes (140 — 170°):

Dial up -20 sec, advance;
Dial down -26 sec, advance;
Crown up -60 sec, advance;
Crown right -80 sec, advance;
Crown down +40 sec, lag;
Crown left +60 sec, lag.

2. At large amplitudes (280 — 320°):

Dial up -35 sec, advance;
Crown up +30 sec, lag.

The difference between the errors in the two horizontal positions (small amplitudes) is:

$-26-(-20)=-6$ sec (advance).

The average error in the two horizontal positions is:

$$\frac{-20+(-26)}{2}=-23 \text{ sec (advance).}$$

The average error in the four vertical positions (small amplitudes) is:

$$\frac{(-60)+(-80)+40+60}{4}=-10 \text{ sec (advance).}$$

Using a special table we find that the weight of screw No. 4 should be reduced.

Since the average error is negative in the two positions, the watch will advance. This should be taken into account when re-poising the balance. If we reduce the weight of the screw in the heavy sector, we also reduce the moment of inertia of the balance, and the re-poised watch will advance even more. In such cases the inverse procedure is used, of adding to the weight of the opposite screw; this will both poise the system and improve its oscillation rate. As a rule, the displaced center of gravity does not coincide with the position of any of the screws and it is usually necessary to reduce or increase the weight of two adjacent screws.

The center of gravity of the balance is most conveniently determined by means of a differential instrument. A nomograph consisting of coordinate axes, a number of concentric circles, and a diagram of the balance and screws of "Pobeda" watches, is traced on the instrument scale (Figure 59). The origin of the coordinates is located at the balance center, and the axes are directed along the lines connecting screws 1 and 9, and 5 and 13. This selection of the axes corresponds to an equilibrium position of the balance with the crown up. Points of intersection of the axes with the concentric circles are marked in seconds and in mm (adjusting-washer thickness). Two "mobile" coordinate axes (metal wires) are mounted in front of the scale.

The instrument panel has four knobs, located in two pairs and provided with scales with 24 divisions each, numbered 0–20–40–60–80–100–120 sec to the left and to the right. A diagram of the watch in the appropriate test position in the P-12 instrument appears below each scale.

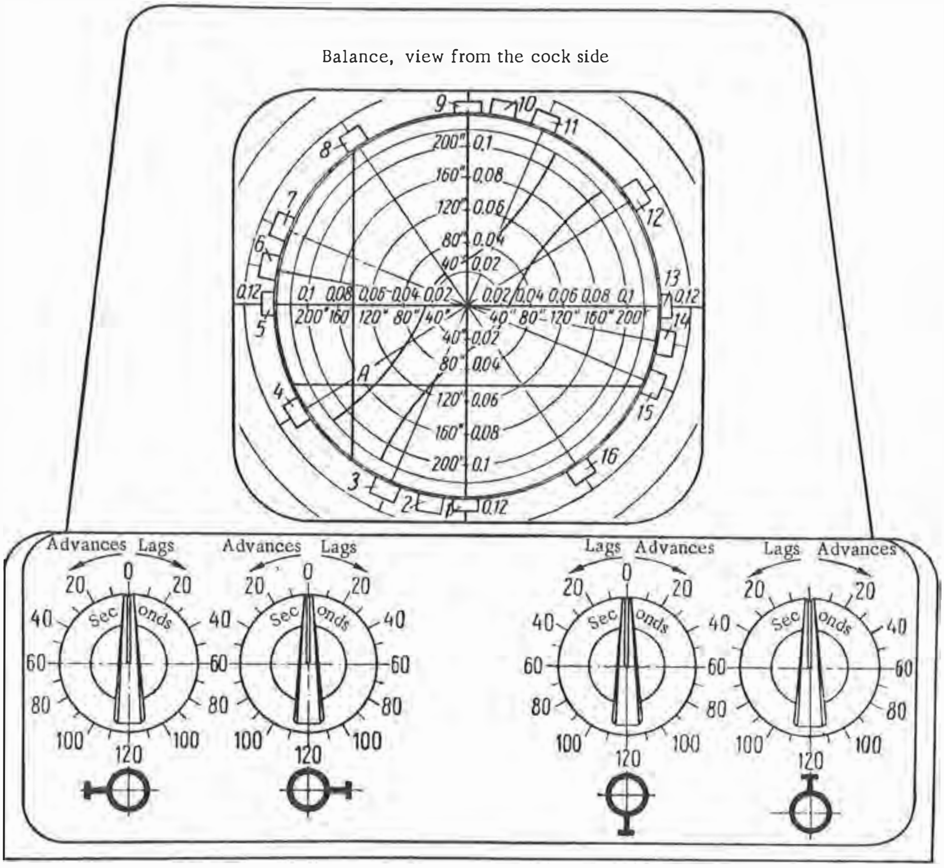


FIGURE 59. Instrument for the determination of the magnitude and direction of displacement of the center of gravity of the balance-hairspring system

The right-hand knobs are kinematically connected with the horizontal mobile coordinate axis and the left-hand knobs are connected with the vertical axis. Rotation of a knob by a definite number of seconds on its scale produces a displacement of the corresponding mobile axis on the nomograph by the same number of seconds. Each knob displaces the axis it is associated with independently of the other. Daily errors of up to 2 min can be marked in each of the four positions on the nomograph.

The center of gravity of the balance is determined as follows:

1. The difference between the daily errors in two opposite directions (for instance, crown up and crown down) is determined in the P-12 instrument at an amplitude of 140 to 170°.

In the example considered earlier, this difference will be -60 - (+40) = -100. The two right-hand knobs are rotated until the mobile abscissa is lowered from ordinate 0 to ordinate 100 sec.

2. Next, the difference between the daily errors in the other two opposite directions – crown right and crown left – is calculated. In our case: -80 - (+60) = -140. The two left-hand knobs are rotated till the mobile ordinate is displaced from abscissa 0 to abscissa 140 sec to the left. The point of intersection of the two mobile axes determines the center of gravity. In our case, this will be point A which is in the zone of screw No. 4 and on the circle indicating a washer thickness of 0.08 mm.

Instead of removing a washer 0.08 mm thick from under screw No. 4, it is better to remove a 0.04 mm thick washer, and to add a washer of the same thickness under the opposite screw, No. 12. In this way the oscillation frequency is not disturbed. The weight of screw No. 4 could also be reduced by drilling the head.

After the balance system has been poised, the daily errors are determined again in the P-12 instrument. If the position adjustment gives satisfactory results, a fine adjustment is performed by means of the regulator. It is recommended that watches be set for a 5 to 10 sec advance in horizontal position to compensate for the watch lag in the vertical positions.

The following results were obtained after a washer 0.04 mm thick had been placed under screw No. 12 and an identical washer had been removed from under screw No. 4: crown up +40 sec (lag), crown down +30 sec (lag), crown right +30 sec (lag), crown left +40 sec (lag). The watch lagged in all positions, and therefore it could be adjusted by means of the regulator. After this fine adjustment, the daily errors of the watch in the various positions were:

Position of the crown	up	down	right	left
Daily error	+5 sec	-5 sec	-5 sec	+5 sec

This accuracy is considered satisfactory. The spring is then fully wound and the watch is finally tested in horizontal and vertical positions at an amplitude of 280 to 320°.

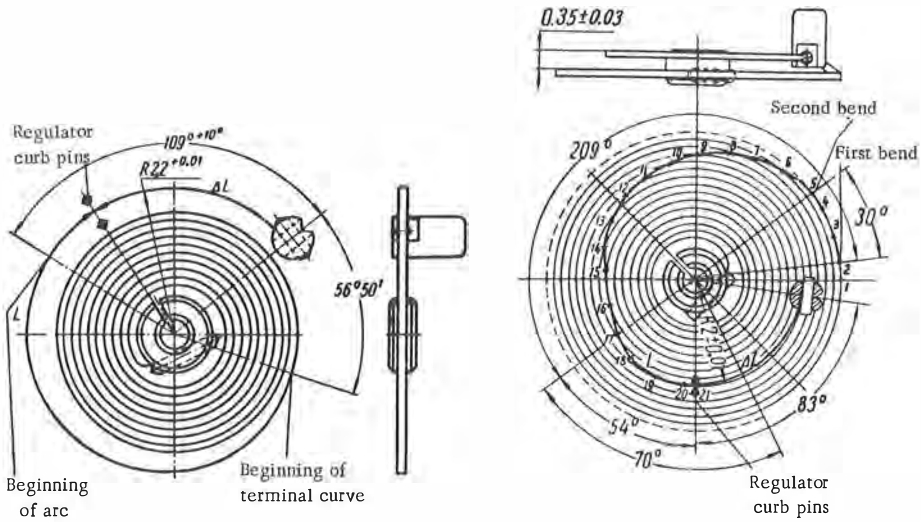
Influence of the clearance in the regulator curb pins and of the hairspring terminal curves on watch accuracy. The function of the regulator curb pins is to alter the effective length of the hairspring, and therefore the watch motion. The daily watch motion can be altered within the limits of ±3 min by displacing the regulator to its extreme positions. The regulator with curb pins was designed for fine adjustment of the watch during overhaul, this being a much simpler and more reliable operation than changing the balance weight. GOST specifies that the regulator of a new watch should not be displaced from its central position by more than 1/3 or 1/4 of its maximum travel.

The clearance between the regulator curb pins and the spring considerably influences the watch motion. This influence depends on the balance amplitude. Some clearance between the pins is of course necessary to prevent the pins from touching the hairspring when the regulator is rotated.

The influence of the clearance between the regulator curb pins on the watch motion as a function of the amplitude is best illustrated by the following examples.

Let the hairspring be situated, in the equilibrium position of the balance, at an equal distance from the two pins and with considerable clearance (Figure 60, a).

At small amplitudes, the hairspring will touch the pins neither in coiling up nor in uncoiling, i. e. the effective hairspring length (L), plus the length from the curb pins to the fastening stud (ΔL) will participate in the operation. With larger amplitudes, the hairspring will touch one or the other of the pins at times and either the entire hairspring length ($L + \Delta L$), or its effective length only will participate. Since the balance period increases with the hairspring length (see formula (6)), for the situation under discussion, it will obviously be smaller at large amplitudes than at small amplitudes.



a b

FIGURE 60. Shapes of the hairspring outer terminal curve:

a–flat spiral; b–Breguet spiral.

If the hairspring contacts one of the pins in the equilibrium position of the balance, then the effective hairspring length will participate at small amplitudes and the entire hairspring length ($L + \Delta L$) will participate at large amplitudes for a considerable part of the oscillation.

The balance period will then be smaller for small amplitudes than for large amplitudes. The position of the hairspring between the regulator curb pins will have no influence on the watch motion, if it is fastened rigidly between them. This system is used in certain watch designs but its use has been restricted by the complications it causes in its use.

The gap between the regulator curb pins is established as 1.5 to 2 times the hairspring thickness to ensure correct functioning of the balance sub-assembly and minimum influence of the clearance on the watch accuracy. A total clearance of 50 to 100% of the hairspring thickness for both sides of the spiral gives the necessary freedom, that is, allows the displacement of the regulator curb pins without disturbing the position of the hairspring terminal curve, and a clearer display of the balance equilibrium position, on the other hand.

Pocket- and wristwatch hairsprings, as mentioned earlier, present inner and outer terminal curves. Their function is to bring the center of gravity of the hairspring nearer the axis of revolution of the balance. The most widely used of the various possible outer terminal curves is the one shown in Figure 60, b. The curve is plotted according to the points whose coordinates are given in Table 4.

TABLE 4

Coordinates of points on the outer terminal curve of wristwatch hairsprings

No. of points	x	y	No. of points	x	y
1	+2.710	0.000	11	−0.936	+1.910
2	+2.710	+0.284	12	−1.330	+1.545
3	+2.600	+0.813	13	−1.600	+1.082
4	+2.370	+1.300	14	−1.710	+0.556
5	+2.030	+1.720	15	−1.710	+0.140
6	+1.612	+2.040	16	−1.625	−0.515
7	+1.110	+2.260	17	−1.490	−1.030
8	+0.597	+2.360	18	−1.250	−1.502
9	+0.064	+2.330	19	−0.786	−1.814
10	+0.462	+2.170	20	−0.273	−1.950
			21	0.000	−1.985

In some watches, the outer terminal curve lies in the hairspring plane, its end of course being led between the pins. The center of gravity of such a hairspring is farther from the axis of revolution and therefore such watches are harder to adjust to a higher degree of accuracy (10 to 20 sec).

Best results are obtained in the adjustment of watches with such a curve if the place where the hairspring passes between the pins is at a distance of 90° or 270° from the place where the inner terminal curve ends (Figure 60, a).

The inner terminal curve is made so that its initial section will not touch the collet when the hairspring is coiled up 330°. Its effective length thus remains constant. The inner terminal curve lies in the hairspring plane. When the watches are adjusted, attention should be paid to the correct positioning of the hairspring relative to the balance.

THE P-12 WATCH TIMER AND ITS USE

The P-12 watch timer (Figure 61) was designed for testing watch accuracy and for measuring the oscillation rate of the balance-hairspring system. It consists of a microphone, an amplifier, an electromagnet, a paper-tape recorder, a synchronous electric motor, and a stroboscope (Figure 62).

The sensing device used is a piezoelectric microphone which transforms the mechanical impacts in the balance system into current pulses. The microphone is specially mounted to permit watch testing in six different positions. The oscillation rate is determined by a head which works on the same principle as the microphone.

The amplifier is a separate unit. The current pulses are amplified and a thyratron activates the electromagnet and through it the recording device or the stroboscope neon lamp.

The synchronous electric motor is fed from the frequency-stabilized a. c. mains (127 v, 50 c). Test results are either recorded on a paper strip or visually observed on the stroboscope. Inspection is carried out by checking the frequency of the balance-hairspring system by means of the stroboscope disk or the printing device driven by an a. c. source with quartz-stabilized frequency. The instrument operates as follows.

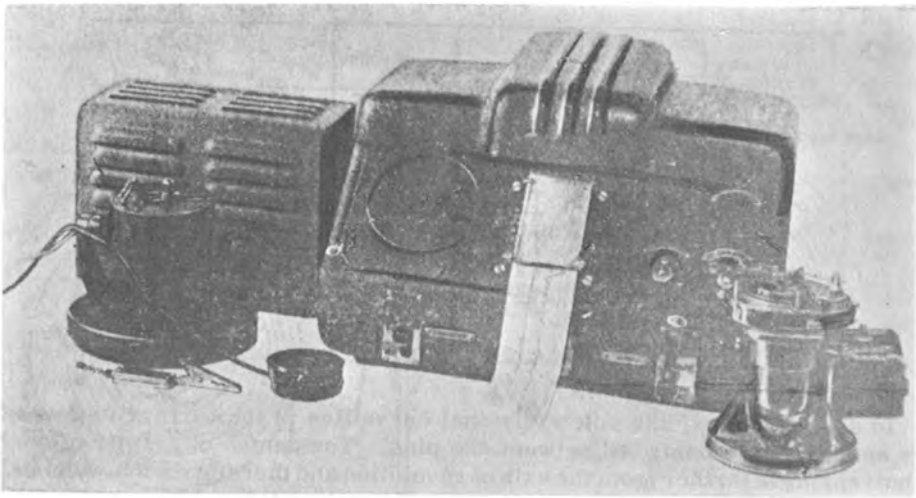


FIGURE 61. P-12 watch timer

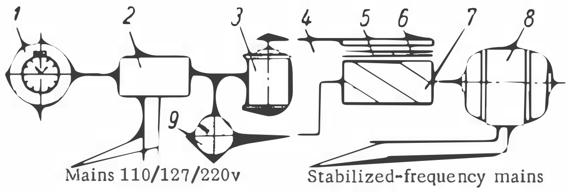


FIGURE 62. Block diagram of the P-12 watch timer:

1–microphone; 2–amplifier; 3–electromagnet; 4–armature; 5–carbon ribbon; 6–paper tape; 7–drum with six helical pro- - jections; 7–synchronous electric motor; 9–stroboscope.

The synchronous motor (1) (Figure 63) drives the drum (2) with six helical projections, and the paper-feeding mechanism (3). The electromagnet attracts the armature (Figure 62) each time it is energized by a current pulse. The armature presses the carbon ribbon and paper strip against the drum and the helical projection leaves a series of dots on the moving paper strip. If the helical projection on the drum is at the same position for each armature stroke, all the dots will obviously be located on the same straight line parallel to the strip edges (Figure 66, a). If the watch is fast, the second stroke will come before the projection has had time to return to its initial position, and the dots will form a line inclined to the right. If, on the other hand, the watch lags, the line of dots will be inclined to the left. The daily error for the watch is determined from the slope of the line, with the aid of a special rotatable scale and the general shape of the line (it is not always straight) makes it possible to draw conclusions as to the probable watch defects. The error determined by the instrument is not the actual 24-hour error but a relative error which corresponds to the condition of the watch movement at the moment of testing. If the daily error is more than ± 10 min, the inspection is conducted by means of the stroboscope. The stroboscope disk (Figure 63) is rotated by a synchronous electric motor at a speed equal to half the drum speed. A neon lamp, lighting up when the electromagnet closes its circuit, is fastened to the disk. A scale is placed in front of the disk and, if the watch is accurate, the lamp is always lighted up at the same disk position relative to the scale. If the watch is fast, the lamp flashes on the disk will move clockwise; if it lags, they will move anticlockwise. The preliminary test of the balance-hairspring system (during the assembly) is also conducted by means of the stroboscope. The accurate final test is recorded on the paper strip. Chronometers and very accurate watches are inspected using a slower strip speed (1/10 of the standard speed). This increases the slope of the line, and the result read on the instrument scale should be divided by 10.

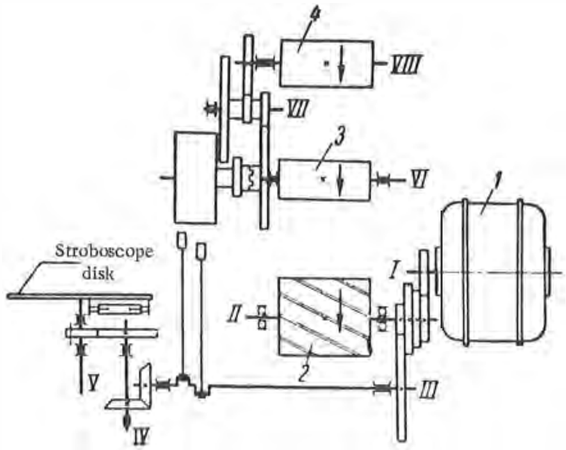


FIGURE 63. Kinematic diagram of the P-12 instrument:

1–synchronous electric motor, 2–drum with helical projections; 3–paper-strip feed drum; 4–carbon-ribbon feed drum; 5–stroboscope disk.

Analysis of watch-timer recordings. The recording pattern can serve not only for determining the watch accuracy, but also for determining the assembly quality. Before considering this aspect, however, we must have an idea of the noise pattern accompanying balance operation. Figure 64 shows three positions of the lever escapement in which noise is produced. Figure 64, a shows the "locking" position of the pallet and wheel when the balance, moving in a free descending motion toward the equilibrium position, strikes the right side of the fork notch with the impulse pin. This is the first impact, producing noise A, which we will call the unlocking noise. This is the most accurate and clearly defined noise.

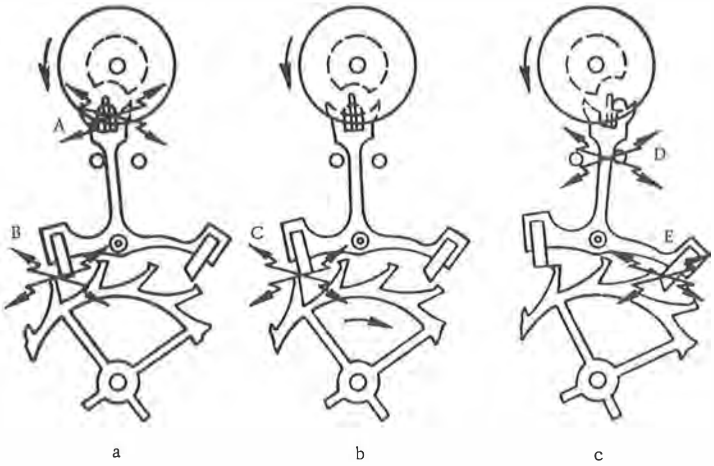


FIGURE 64. Three lever-escapement positions causing noise in watches

The pallet lever in rotating through locking angle, draws the escape-wheel tooth back. A new, slight noise, B, is superposed on the unlocking noise.

The escape-wheel tooth then passes from the locking to the impulse face of the pallet, the ensueing impact producing the so-called impulse noise, C. This instant is shown in Figure 64, b. If the impulse pin has considerable clearance in the fork notch (above 0.1), additional noises are produced which are weaker than the impulse noise. Figure 64, c shows the instant when the pallet lever strikes the right-hand banking pin. A strong noise, D, is produced and is followed almost immediately by a noise E of roughly the same intensity caused by the dropping of the escape-wheel tooth on the discharging-pallet locking face. The resultant noise is known as drop noise and is the most intense of all. The three dominant noises are thus: unlocking noise A, impulse noise C, and drop noise D.

To permit the watch accuracy to be evaluated from the recording, the dots printed on the strip should all correspond to the same noise. It is preferable that they correspond to the unlocking noise because it has the most accurate period.

Figure 65 shows oscillograms of watch-movement noises. The letters correspond to the noises discussed above.

The voltage necessary for triggering the thyratron is shown on the oscillogram by a dotted line. Sound D in the left-hand oscillogram will obviously actuate the electromagnet. In the case of the higher noise level shown in the right oscillogram, the voltage necessary for triggering will be attained both in A and in D. Thyratrons are characterized by the fact that they can produce only a specified number of pulses per second, which number is only slightly higher than the number of balance oscillations. Therefore, only the first noise A – the unlocking noise – will actuate the electromagnet and cause the appearance of a dot on the paper strip.

If the amplification is too high, the instrument will print extraneous noises and thus distort the indications. This must be kept in mind when analyzing the recording.

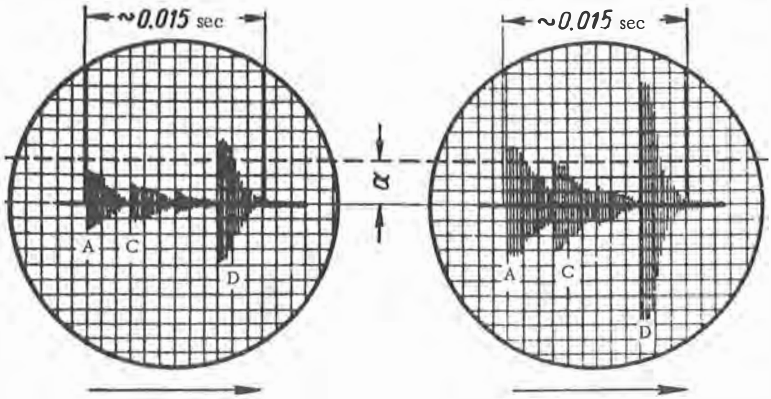


FIGURE 65. Oscillograms of watch noise

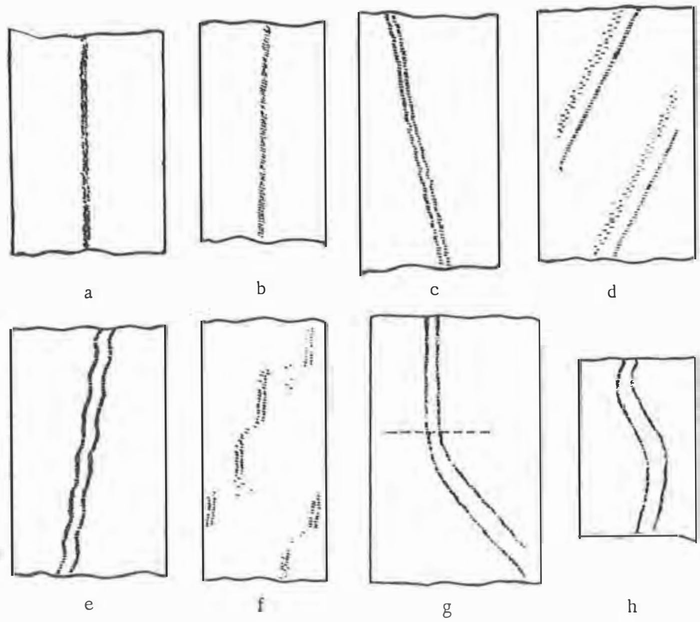


FIGURE 66. Watch-timer recordings

Figure 66, b shows a recording of a watch which is fast by 5 sec in 24 hours. The two half-periods of the balance are equal. The hairspring is well poised. One continuous line is obtained on the diagram.

The watch recorded in Figure 66, c lags by 15 sec in 24 hours. Two adjacent lines appear on the diagram, and they indicate a certain one-sidedness in the oscillation. The watch motion is even. The distance between the lines will be greater, the smaller the amplitude of the balance oscillations.

In Figure 66, d the watch is fast by 25 sec in 24 hours. The fork is impacted with one of the pallets being in different positions. This is probably due to a small drawing angle, or a chipped pallet edge.

The watch recorded in Figure 66, e is fast by 10 sec in 24 hours. The escape wheel has peripheral run-out. Periodic waves on the diagram generally indicate incorrectly produced toothed wheels. The defective wheel is easily located from the band speed and the distance between adjacent waves.

The watch recorded in Figure 66, f exhibits a "knock", as can also be observed from the peculiar noise in the watch. The watch advances at each knock and the recording line moves to the right.

Figure 66, g shows a case of disturbance of isochronism upon changing of the watch position from horizontal to vertical. The daily error is zero in horizontal position, while the recording corresponding to the vertical position is increasingly inclined to the left as a result of the gradual drop in amplitude. The balance is nonisochronous. The recording may revert to the vertical position if the amplitude becomes stable in a new position, and the balance is well poised.

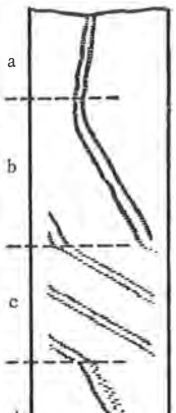


FIGURE 67. Watch-timer recording for various positions of the watch

The recording in Figure 66, h is characterized by the so-called varying error, where the balance does not receive sufficient energy and the amplitude is not constant. The mesh between the center wheel and the third pinion is defective. Figure 67 shows a watch recording taken in the following positions:

a– horizontal, the watch advances 5 sec;
b– vertical; crown left, the watch lags 30 sec;
c– vertical, crown up, the watch lags 85 sec;
d– vertical, crown right, the watch lags 30 sec;
e– vertical, crown down, the watch advances 85 sec.

The daily mean error for the vertical positions will be: $\frac{+30-85+85+30}{4} = 15$ sec (lag).

A change from horizontal to vertical position will be accompanied by a change in the various indications of $+5-(-15) = +20$ sec. A change from vertical to horizontal will be accompanied by a change of $-15-(+5) = -20$ sec. The balance is therefore unpoised, and the amplitude of the vertical position is less than 220°. It was mentioned earlier that the watch will lag at small amplitudes if the center of gravity is above the balance staff, and vice versa. It can be easily determined which screw must have its weight reduced in order to correct the unbalance.

Recordings such as those described above make it possible to identify assembly defects in the main elements of the watch movement: the balance, the escapement, the wheel train, and the barrel and mainspring. Examples could be cited to illustrate other assembly defects encountered, such as the seconds hand brushing the dial, defective jewels, etc.

It was earlier mentioned that the measurement of the oscillation rate for the balance-hairspring system is accomplished on the P-12 watch-timer with the aid of a special head (see Figure 69) provided with a standard watch movement (Figure 68). The lower journal of the balance to be adjusted (1) is set in a fixed bearing consisting of two suitably mounted rubies. The upper journal is supported in the hinged bearing (2) with similar rubies. To ensure correct positioning of the impulse pin in the pallet-lever fork notch, especially after the hairspring length has been altered, the table carrying the standard watch movement can be rotated about axis (3), which is coaxial with the balance staff. The head is provided with a piezoelectric microphone, and its operation is basically similar to that of the normal instrument, the only difference being that the head body is additionally equipped with chucking and cutting devices for the hairspring and stud and can therefore perform the following operations: adjustment of the hairspring length to achieve the proper oscillation rate, pinning of the hairspring end in the stud, and cutting the superfluous ends of hairspring and pin. Rubber padding between the standard watch movement and the table reduces the absorption of sound pulses by the head mass. The procedure is as follows (Figure 69):

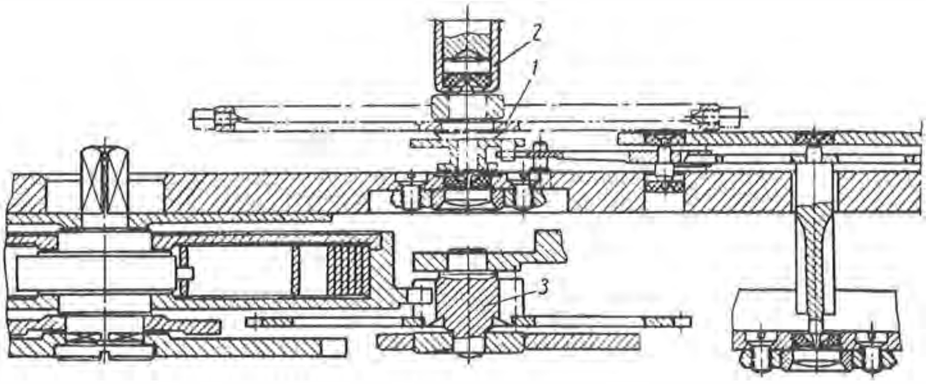


FIGURE 68. Standard watch movement of the P-12 watch-timer head

1. The balance with hairspring is mounted in the bearings.
2. Lever (6) which opens jaws (12) is pressed downward. The stud is set, oriented relative to the hairspring, and then clamped in the jaws by the release of lever (6). Lever (6) is then displaced laterally in the direction of arrow m. This displaces jaws (12) to its extreme working position, adjustable through screw (9).
3. Eccentric (7) is rotated to position C, thus opening jaws (12). The hairspring end is drawn by pincers through the jaws introduced into the stud hole through the feeding jaws (5), and finally into the slot in pin (4), where it is fastened by rotating the wheel (3).
4. Lever (6) is pressed again, freeing the stud which is then aligned with the hairspring. The stud is then clamped again.

5. The hairspring is clamped by rotating eccentric (9) from position C to position A.

6. The balance is started, and the correct interaction between balance and escapement achieved by rotating wheel (2). The hairspring is then freed slightly by rotating the eccentric to position B.

7. Vibration is checked by means of the stroboscope. The hairspring length is varied by rotating wheel (3) and winding the superfluous hairspring onto pin (4). Wheel (2) is simultaneously rotated to maintain the correct interaction between the balance and escapement.

8. After the hairspring length has been thus determined, the hairspring is clamped in jaws (11) by rotating the eccentric (7) back into position A.

9. The hairspring pin is introduced into slot (8), and lever (6) is shifted to position n. The pin is then introduced into the stud hole.

10. The superfluous length of the hairspring and pin is cut off by the knife (10). Jaws (11) and (12) are then opened, and the upper bearing (1) and the balance are removed from the head.

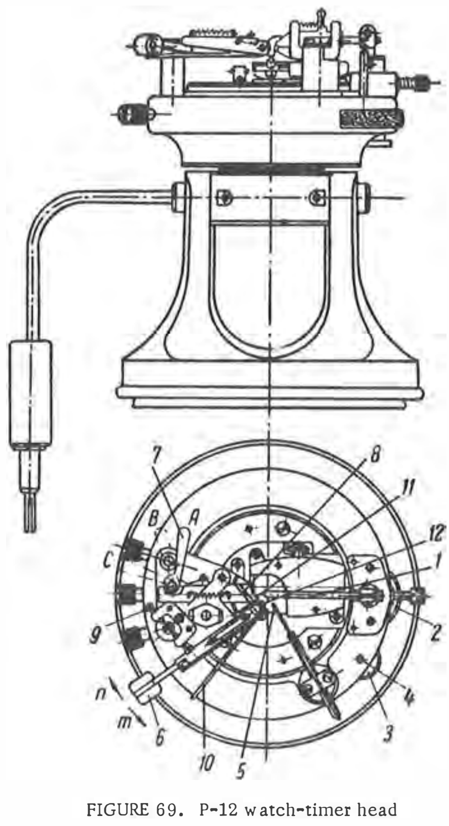


FIGURE 69. P-12 watch-timer head

When the hairspring has an outer terminal curve, the latter is shaped in the next operation (not on the watch-timer head).

Technical data of the P-12 watch timer:

1. Recordable daily errors:

a) at normal strip feed: ±10 min;

b) at slow strip feed: ±1 min;

c) using the stroboscope: ±48 min (the ray being displaced by 180° in 3 sec).

2. Recordable number of oscillations per hour: 9,000, 12,000, 14,400, 18,000, 19,800, 21,600 36,000, 180,000.

3. Number of oscillations per hour observable by stroboscope: 9,000, 18,000, 19,800, 36,000.

4. Current supply of synchronous electric motor: frequency-stabilized a. c. mains 127 v, 50 c.

5. Current supply of the instrument amplifier: 110/127–220 v.

6. Stroboscope-disk diameter: 70 mm.

Other instruments are also in use for watch-accuracy inspection. The PPCh-4 watch timer, which also records the daily error on a synchronously rotating drum is an example. Either diagram paper or a plexiglass sleeve is placed on the drum. The diagram paper with the printed recording is torn off after the recording is completed, while the line recorded on the plexiglass sleeve is easily erased.

The working principle of the PPCh-4 watch timer is the same as that of the P-12 watch timer.

INSPECTION OF POCKET AND WRISTWATCHES ACCORDING TO GOST

After the watches have been assembled on the conveyor line, and adjusted on the P-12 or PPCh-4 watch timer, they are sent to the inspecting-testing station, where they are subjected to extended accuracy and reliability tests.

The watches are tested in six positions in the first testing cycle, and in four positions in the last cycle, all in accordance with GOST requirements. The tests run in the inspecting-testing station establish the actual 24-hour error in each of the positions. The watches are wound daily, and the time indicated on the dial at each winding is recorded. The time indicated by the watch is compared with that indicated by a chronograph or a standard watch, and the result is recorded in a notebook. Some plants use a mechanized system for feeding the watches to the operator workplace: the watches are put, dial up, in open boxes, 10 watches per box, and are placed on an intermittent conveyor belt at exactly the same time (accuracy 5 sec).

The conveyor belt is staffed by 10 operators. A shield with ten windows is installed above the belt in such a manner that only one specific watch is seen from each window. Thus, the operator occupying the sixth position will see through his window only the watch placed in the sixth cell of the box. The watch readings are recorded on a card.

This type of organization for the recording of watch indications frees the operator from the need to compare these indications with those of a chronometer or a reference watch.

The conveyor rate is maintained automatically by a reference clock provided with a special contact device for sending pulses to the conveyor control panel.

After the watches pass accuracy tests in the various positions, they undergo a test which determines their time of operation from one winding, and they are inspected for absence of external defects. A certificate of standardized form is then written out for each watch, the watches are packed in boxes and sent to the finished-products storage area from where they are eventually shipped.

Watch-accuracy inspection chart

No.	Initial position	First day		Second day		Third day		Fourth day		Duration of watch operation	Conclusion
	watch reading	watch reading	daily error	watch reading	daily error	watch reading	daily error	watch reading	daily error		
1	11^{55}	12^{25}	$+0^{30}$	11^{35}	-0^{50}	11^{35}	0	11^{55}	$+^{20}$	38	Rejected
2	13^{55}	13^{45}	-0^{10}	13^{45}	-0	13^{50}	$+0^{05}$	13^{15}	-0^{35}	37	Approved
3	14^{0}	14^{10}	$+0^{10}$	14^{20}	$+0^{20}$	14^{40}	$+0^{20}$	15^{20}	$+0^{40}$	38	"
4	12^{25}	12^{40}	$+0^{25}$	12^{45}	$+0^{05}$	13^{10}	$+0^{25}$	13^{45}	$+0^{35}$	36	"
5	12^{50}	13^{10}	$+0^{20}$	13^{40}	$+0^{30}$	14^{05}	$+0^{25}$	14^{20}	$+0^{15}$	36	"
6	13^{05}	13^{10}	-0^{05}	13^{20}	$+0^{10}$	13^{40}	$+0^{20}$	13^{55}	$+0^{15}$	37	"
7	12^{20}	12^{25}	$+0^{05}$	12^{50}	$+0^{25}$	13^{10}	$+0^{20}$	13^{20}	$+0^{10}$	38	"
8	12^{45}	12^{25}	-0^{20}	12^{20}	-0^{05}	12^{10}	$+0^{10}$	12^{35}	$+0^{25}$	37	"
9	14^{05}	14^{15}	$+0^{10}$	14^{50}	$+0^{35}$	15^{10}	$+0^{20}$	14^{40}	-0^{30}	37	"
10	12^{40}	12^{20}	-0^{20}	12^{30}	$+0^{10}$	12^{40}	$+0^{10}$	12^{50}	$+0^{10}$	38	"

CONCLUSION

The manufacturing processes of all engineering industries are continuously being improved: old processing methods are replaced by new and more advanced methods, and manual operations are mechanized and automatized.

Research and design work on the development of new, highly productive machining and assembly processes is being conducted by the watch industry in all possible directions. The latest achievements of science and technology are being applied: ultrasonic frequencies, 100 kv electrostatic fields, radioactive isotopes, and electronics. Automatic lines and unit-built machines are being introduced into production, and automation of finishing, assembly and adjusting operations is being developed.

An automatic line for machining wristwatch case middles is already in existence (1956) and is in use in the production of "Pobeda" watches. The line was designed for an output of 3,000 parts per shift, or 1.8 million parts yearly on a two-shift basis. The over-all line productivity exceeds six times the productivity of its component equipment. The line is divided into two sectors: the first sector performs the six turning operations, and the second sector the four drilling and countersinking operations. Each part is fed into the work zone of the next machine after it has been machined on the previous machine of the line and is rotated if necessary by automatically operated fixtures and rotating attachments. The machining cycle is 8 sec: 4 sec are spent on the actual machining, and 4 sec on transportation. Magazines are installed at the beginning of the line and between its two sectors, their functioning being to feed (for some time) an uninterrupted flow of machining blanks to the second sector if the first sector has stopped for any reason.

A 0.5 to 1% sample is inspected within the line. Five part samples are removed at the end of each sector and fed to automatic inspecting instruments.

Chips are removed from the machines and the working surfaces by compressed air. Should a drill happen to break, the sector stops automatically, and a light signal indicates the place of breakage.

The line elements are so designed that the separate units or sections can be readjusted to form a flow line which will turn out case middles or lids and bezels of various sizes. The line process remains basically unchanged if the case middle is manufactured by precision casting or by press forming.

Automatic lines are a natural stage in the development of mass-production methods and processing means. An automatic line sharply increases the productivity and radically alters the structure and planning of production in the given sector. The automatic line has replaced machine lines in which the different types of machines were interconnected by various transporting devices, allowing a flow of parts.

A problem which must be solved in the nearest future is the manufacture of watch parts requiring a small number of operations, such as the hairspring collet and stud, or the cannon pinion, in unit-built machines, which will perform in one machine all the operations necessary for the manufacture of the part (turning the blanks, drilling and countersinking holes, milling slots and faces, and deburring). Such methods increase productivity by approximately four times because of the reduction in the auxiliary time required for mounting and fastening the part, starting and stopping the machine, and removing the part. Parts machined in one chucking are also more accurate, and the losses in the setup are reduced.

Unit-built machines should also be used for performing a group of operations on parts requiring a large number of operations, such as plates, bridges, balances, pallet levers, etc. For instance, all the milling operations in the manufacture of the pallet lever should be performed by the same unit-built machine.

Automatic equipment is being designed for the electroplating shops. Automatic machines will not only replace the manual dipping of parts (now used in copper, nickel and zinc plating), but will also perform the preliminary operations, the basic electroplating operations, and the rinsing operations which follow plating.

A hermetically sealed mechanism for the automatic painting of alarm-clock cases in a 100 kv electrostatic field is in the design stage. An uninterrupted flow of cases is subjected to surface preparation, painting and drying operations in succession.

Painting in an electrostatic field has an advantage over spray painting in that it wastes less of the expensive enamels and it also gives a better-quality coating. The time taken by the operations is also reduced.

An automatic machine for grinding and polishing the case parts of watches is also being designed. Its introduction will not only increase the production rate by 2 to 3 times, but will also considerably improve work conditions.

Washing operations represent a considerable fraction of the work expended in watch production. Parts are washed after individual operations and also before being returned to processing from the stores where they are kept in an oiled state. Almost 200 washing operations are included in the manufacturing process of wristwatches. One watch plant uses, with considerable success, a 20 kc ultrasonic vibrator for washing of parts in soap solutions. The washing time in an ultrasonic installation is reduced to a third or a fourth in comparison with the usual methods. The quality of the washing is better and the amount of washing solution used is smaller.

Considerable effort is also being invested in the modernization of metal-cutting machines. This is a field which does not involve large expenses or extensive experiments.

The improved versions of the S-81A and S-57A machines which are being designed have orientable spindle stops, higher speeds and spindles which are free of belt-created radial stresses. The machine productivity increases by about 20%.

The improved S-50 machine has 12 camshaft speeds instead of 6, and the cycle time is variable from 5 to 128 sec. The machine is driven by a high-frequency electric motor revolving at 12,000 rpm. Productivity is increased by about 30%.

Additional attachments are being mounted on the S-8a and S-15 machines, which stop them automatically the moment the specified part dimension is attained. The productivity of these machines is increased by about 15%.

Assembly operations involving detachable and nondetachable joints constitute from 40 to 50% of the work involved in watch manufacture. Attempts to mechanize and automate these operations are therefore only natural and machines resulting from these efforts which are already in operation are the D-246 press and the P-32 instrument.

An experimental five-spindle automatic machine has been designed and built to replace the S-195 press (Figure 13, Chapter X) for pressing home jewels in plates and bridges. This machine performs the following operations automatically: oriented feed of the plate or bridge from the magazine to the pressing station, oriented feed of jewels from the magazine, pressing of jewels into plates in successive order and, lastly, removal of the plate.

An experimental prototype of a semiautomatic machine for the final assembly of the barrel subassembly has been built.

The winding crown will be automatically screwed onto the stem, increasing the production rate for this operation by 150%.

The balance-hairspring system will have its oscillation rate adjusted automatically in the new P-34 electronic timer. This instrument achieves an adjustment accuracy of 5 sec, compared with the 15 sec achieved on the average on the P-12 timer.

Static poising of the balance wheel will be realized in a standard movement to an accuracy of 1 min, compared with the accuracy of 4 to 5 min achieved by poising on knife edges. The time taken by this operation will also be reduced to one half or one third of the time required at present.

The inner and outer terminal curves will also be made in a mechanized process which will produce a more regular geometrical shape. The means of fastening the hairspring in the collet and stud will be changed. This will considerably simplify the eighth assembly operation – the movement starting.

The guard clearances between the pallet lever fork and the balance double roller will be established without the balance. The position of the pallet lever horns and the guard pin in the movement will be determined by the projection method. The lever position will be projected on the screen of a profile projector installed at the workplace and compared with a drawing placed on the screen. This method will increase the rate and accuracy of the assembly operations and make unnecessary the mounting of the balance in the fourth operation.

Lubrication of the watch movement will be performed by a device which will feed specified amounts of oil to specified points in the movement. The bridges will be set by pneumatic devices.

All parts requiring a large number of operations such as the plate, dial, balance, case, etc, will be processed by the flow-line method. In many cases this will require changes in the methods of processing the parts. For example, the manually operated machine used for printing scales on dials will be replaced by an automatic machine, dial-surface polishing will be automated, etc.

The basic technical measures listed above, in conjunction with organizational measures, such as the fixed time rate for operations, and with considerable broadening of specialization and cooperation between various elements of the production, will make it possible to raise the level of watch-manufacturing technology.

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APPENDIX 1

Table of the values of Φ_z

The first column gives the value of z to the first decimal place and the numbers at the heads of the columns are the second decimal. The columns other than the first give the values of Φ_z*

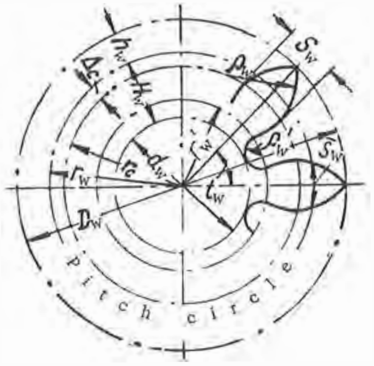
	0	1	2	3	4	5	6	7	8	9
0.0	0.0000	0.0080	0.0160	0.0240	0.0320	0.0398	0.0478	0.0558	0.0638	0.0718
0.1	0786	0876	0956	1034	1114	1192	1278	1350	1428	1506
0.2	1586	1664	1742	1818	1896	1974	2052	2328	2206	2282
0.3	2358	2434	2510	2586	2662	2736	2812	2836	2960	3034
0.4	3108	3182	2386	3328	3400	3472	3544	3616	3688	3758
0.5	3830	3900	3970	4038	4108	4176	4246	4314	4380	4448
0.6	4514	4582	4648	4714	4778	4844	4908	4972	5034	5098
0.7	5160	5222	5284	5346	5408	5468	5528	5588	5646	5704
0.8	5762	5820	5878	5934	5910	6046	6102	6156	6212	6266
0.9	6318	6372	6424	6476	6528	6578	6630	6680	6730	6778
1.0	6826	6876	6922	6970	7016	7062	7108	7154	7198	7242
1.1	7286	7330	7372	7416	7458	7498	7540	7580	7620	7660
1.2	7698	7738	7776	7814	7850	7888	7924	7960	7994	8030
1.3	8064	8098	8132	8164	8196	8330	8262	8294	8324	8364
1.4	8384	8414	8444	8472	8502	8530	8558	8584	8612	8638
1.5	8664	8690	8714	8740	8764	8788	8812	8936	8856	8882
1.6	8904	8926	8948	8968	8990	9010	9030	9050	9070	9090
1.7	9108	9128	9146	9164	9182	9198	9216	9232	9250	9266
1.8	9282	9298	9312	9328	9342	9356	9372	9386	9398	9412
1.9	9426	9438	9452	9464	9476	9438	9500	9512	9522	9534
2.0	9544	9556	9566	9576	9586	9596	9606	9616	9624	9634
2.1	9642	9652	9660	9668	9676	9684	9692	9700	9708	9714
2.2	9722	9728	9736	9742	9750	9756	9762	9768	9774	9780
2.3	9786	9792	9796	9802	9808	9812	9818	9822	9826	9832
2.4	9836	9840	9844	9850	9854	9858	9862	9864	9868	9872
2.5	9876	9880	9882	9886	9890	9892	9896	9898	9902	9904
2.6	9906	9910	9912	9914	9913	9920	9922	9924	9926	9928
2.7	9930	9932	9934	9936	9938	9940	9942	9941	9946	9948
2.8	9949	9950	9952	9954	9955	9956	9957	9958	9960	9962
2.9	9963	9964	9965	9966	9967	9968	9969	9970	9971	9972
3.0	9973	9974	9975	9976	9977	9978	9978	9979	9980	9980
3.1	9981	9982	9982	9983	9983	9984	9984	9984	9985	9985
3.2	9986	9986	9987	9987	9988	9988	9989	9989	9990	9990
3.3	9990	9991	9991	9991	9992	9992	9992	9993	9993	9993
3.4	9993	9994	9994	9994	9994	9994	9995	9995	9995	9995

* To four decimal places

APPENDIX 2

TABLE 1

The profile elements of gear wheel teeth



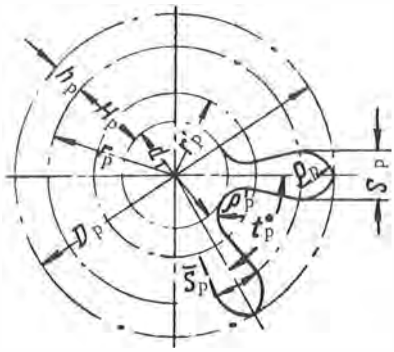
Gearing elements	Symbol	Basic relationships
Module	m	$m = \frac{2r_W}{z_W}$
Number of teeth	z	
Transmission ratio	i	$i = \frac{z_W}{z_P}$
Center distance	A	$A = \frac{(z_W + z_P)\,m}{2}$
Pitch radius	r_W	$r_W = \frac{m \cdot z_W}{2}$
Angular pitch	t°_W	$t^{\circ}_W = \frac{360^{\circ}}{z_W}$
Tooth-face radius	ρ_W	Taken from Table 3
Radius of the circle drawn through the centers of the tooth-face arcs	r_c	$r_c = r_W - \Delta_c$ –where Δ_c is taken from Table 3

TABLE 1 cont'd

Gearing elements	Symbol	Basic relationships
External diameter	D_W	$D_W = 2\left(r_c \cos\beta + \sqrt{\rho_W^2 - r_c^2 \cdot \sin^2\beta}\right)$, where $\angle\beta = \angle\alpha - \frac{t_W}{4}$; $\cos\alpha = \frac{r_W^2 + r_c^2 - \rho_W^2}{2 \cdot r_W \cdot r_c}$
Addendum	h_W	$h_W = \frac{D_W}{2} - r_W$
Dedendum	H_W	$H_W = \frac{t_W}{2} = \frac{\pi \cdot m}{2} = 1{,}57\ m$
Root diameter	d_W	$d_W = 2\,(r_W - H_W)$
Fillet radius	ρ'_W	$\rho'_W = \frac{d_W}{2}\left(\frac{S_m \frac{t_W}{4}}{1 - \sin\frac{t_W}{4}}\right)$
Radius of the circle drawn through the centers of the fillet arcs	r'_W	$r'_W = \frac{d_W}{2} + \rho'_W$
Tooth thickness at the normals to the tooth-face arcs (maximum tooth thickness)	S_W	$S_W = 2\,(\rho_W - r_c \cos\beta)$, where $\beta = \alpha - \frac{t_W}{4}$; $\cos\alpha = \frac{r_W^2 + r_c^2 - \rho_W^2}{2 \cdot r_W \cdot r_c}$
Arc thickness of tooth on pitch circle	$\bar{s}_W$	$\bar{s}_W = \frac{\bar{t}_W}{2} = \frac{\pi \cdot m}{2} = 1.5 \cdot m$

TABLE 2

The profile elements of pinion teeth



<table>
<tr><th>Dimension</th><th>Symbol</th><th colspan="2">Basic relationships</th></tr>
<tr><td>Module</td><td>m</td><td colspan="2">$m = \frac{2r_p}{z_p}$</td></tr>
<tr><td>Number of teeth</td><td>z_p</td><td colspan="2">—</td></tr>
<tr><td>Transmission ratio</td><td>i</td><td colspan="2">$i = \frac{z_w}{z_p}$</td></tr>
<tr><td>Center distance</td><td>A</td><td colspan="2">$A = \frac{(z_w + z_p) \cdot m}{2}$</td></tr>
<tr><td>Pitch radius</td><td>r_p</td><td colspan="2">$r_p = \frac{m \cdot z_p}{2}$</td></tr>
<tr><td>Angular pitch</td><td>t_p°</td><td colspan="2">$t_p^\circ = \frac{360^\circ}{z_p}$</td></tr>
<tr><td rowspan="2">Tooth-face radius</td><td rowspan="2">ρ_p</td><td>For pinions with $z \leqslant 10$</td><td>For pinions with $z > 10$</td></tr>
<tr><td>$\rho_p = 0.70 \cdot m$</td><td>$\rho_p = 0.83 \cdot m$</td></tr>
</table>

TABLE 2 cont'd

Dimension	Symbol	Basic relationships	
Addendum	h_p	$h_p = 0.675\, m$	$h_p = 0.800\, m$
External diameter	D_p	$D_p = 2(r_p + h_p)$	
Dedendum	H_p	$H_p = h_w + 0.4m$	
Root diameter	d_p	$d_p = 2(r_p - H_p)$	
Fillet radius	ρ'_p	$\rho'_p = \frac{d_p}{2}\left(\frac{\sin\frac{120^\circ}{z_p}}{1-\sin\frac{120^\circ}{z_p}}\right)$; $\rho'_p = \frac{d_p}{2}\left(\frac{\sin\frac{108^\circ}{z_p}}{1-\sin\frac{108^\circ}{z_p}}\right)$	
Radius of the circle drawn through the centers of the fillet arcs	r'_p	$r'_p = \frac{d_p}{2} + \rho'_p$	
Chordal thickness of tooth at pitch circle	s_p	$s_p = z_p \cdot \sin\frac{60^\circ}{z_p}$; $s_p = z_p \cdot \sin\frac{72^\circ}{z_p}$	
Arc thickness of tooth on pitch circle	$\bar{s}_p$	$\bar{s} = \frac{1}{3}\bar{t}_p$; $\bar{s}_p = \frac{2}{5}\bar{t}_p$	

TABLE 3

Basic dimensions of toothed wheels as a function of the number of pinion teeth and the transmission ratio for m = 1

Number of pinion teeth	Designation	Transmission ratio 5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
6	Δ_c	0.16	0.16	0.17	0.17	0.18	0.18	0.19	0.19	0.20	0.21	0.22
	ρ_w	1.80	1.82	1.83	1.84	1.86	1.88	1.89	1.90	1.92	1.94	1.95
7	Δ_c	0.15	—	0.16	—	0.17	—	0.18	—	0.19	—	0.21
	ρ_w	1.90	—	1.93	—	1.96	—	1.99	—	2.02	—	2.05
8	Δ_c	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.18	0.19	0.20
	ρ_w	2.00	2.02	2.04	2.06	2.08	2.10	2.12	2.14	2.16	2.18	2.20
9	Δ_c	0.13	—	0.14	—	0.15	—	0.16	—	0.17	—	0.19
	ρ_w	2.10	—	2.14	—	2.18	—	2.22	—	2.26	—	2.30
10	Δ_c	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.16	0.17	0.18
	ρ_w	2.25	2.27	2.29	2.31	2.33	2.35	2.37	2.38	2.41	2.43	2.45
11	Δ_c	0.11	—	0.12	—	0.13	—	0.14				
	ρ_w	2.35	—	2.39	—	2.43	—	2.47				
12	Δ_c	0.10	0.10	0.11	0.11	0.12	0.12	0.13				
	ρ_w	2.45	2.48	2.50	2.52	2.55	2.58	2.60				
14	Δ_c	0.08	0.08	0.09								
	ρ_w	2.70	2.72	2.75								
16	Δ_c	0.06	0.06	0.07								
	ρ_w	2.90	2.93	2.96								
18	Δ_c	0.04	—	—								
	ρ_w	3.10	—	—								

APPENDIX 3

Approach for milling toothed wheels and pinions with tooth height

$h_0 = 2.17\ m$

Gear module, mm	0.1	0.12	0.15	0.20	0.25	0.30	0.40	0.50
Tooth height h_0, mm	0.217	0.26	0.33	0.43	0.54	0.65	0.88	1.08
Milling-cutter diameter, mm	Approach, mm							
10	1.45	1.6	1.8	2.0	2.3	2.5	2.8	3.1
12	1.6	1.8	2.0	2.2	2.5	2.7	3.1	3.4
15	1.8	2.0	2.2	2.5	2.8	3.0	3.5	3.9
18	2.0	2.2	2.4	2.7	3.0	3.4	3.9	4.3
20	2.1	2.3	2.6	2.9	3.2	3.6	4.1	4.5
24	2.3	2.5	2.8	3.2	3.6	3.9	4.5	5.0
30	2.5	2.8	3.1	3.5	4.0	4.4	5.0	5.6
35	2.7	3.0	3.4	3.9	4.3	4.7	5.4	6.0
40	2.9	3.2	3.6	4.1	4.6	5.0	5.8	6.5
45	3.1	3.4	3.8	4.4	4.9	5.4	6.2	6.9
50	3.3	3.6	4.1	4.6	5.2	5.7	6.5	7.3

APPENDIX 4

ΔR as a function of the angles $\Delta\beta$ and $\Delta\gamma$

$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR
0°00′	0	0°30′	2.41	1°00′	4.82	1°30′	7.23	2°00′	9.64	2°30′	12.05	3°00′	14.46	3°30′	16.87	4°00′	19.27	4°30′	21.68
0°01′	0.08	0°31′	2.49	1°01′	4.90	1°31′	7.31	2°01′	9.72	2°31′	12.13	3°01′	14.54	3°31′	16.95	4°01′	19.35	4°31′	21.76
0°02′	0.16	0°32′	2.57	1°02′	4.98	1°32′	7.39	2°02′	9.80	2°32′	12.21	3°02′	14.62	3°32′	17.03	4°02′	19.43	4°32′	21.84
0°03′	0.24	0°33′	2.65	1°03′	5.06	1°33′	7.47	2°03′	9.88	2°33′	12.29	3°03′	14.70	3°33′	17.11	4°03′	19.51	4°33′	21.92
0°04′	0.32	0°34′	2.73	1°04′	5.14	1°34′	7.55	2°04′	9.96	2°34′	12.37	3°04′	14.78	3°34′	17.19	4°04′	19.59	4°34′	22.00
0°05′	0.40	0°35′	2.81	1°05′	5.22	1°35′	7.63	2°05′	10.04	2°35′	12.45	3°05′	14.86	3°35′	17.27	4°05′	19.67	4°35′	22.08
0°06′	0.48	0°36′	2.89	1°06′	5.30	1°36′	7.71	2°06′	10.12	2°36′	12.53	3°06′	14.94	3°36′	17.35	4°06′	19.75	4°36′	22.16
0°07′	0.56	0°37′	2.97	1°07′	5.38	1°37′	7.79	2°07′	10.20	2°37′	12.61	3°07′	15.02	3°37′	17.43	4°07′	19.83	4°37′	22.24
0°08′	0.64	0°38′	3.05	1°08′	5.46	1°38′	7.87	2°08′	10.28	2°38′	12.69	3°08′	15.10	3°38′	17.51	4°08′	19.91	4°38′	22.32
0°09	0.72	0°39′	3.13	1°09′	5.54	1°39′	7.95	2°09′	10.36	2°39′	12.77	3°09′	15.18	3°39′	17.59	4°09′	19.99	4°39′	22.40
0°10′	0 80	0°40′	3.21	1°10′	5.62	1°40′	8.03	2°10′	10.44	2°40′	12.85	3°10′	15.26	3°40′	17.67	4°10′	20.07	4°40′	22.48
0°11′	0.88	0°41′	3.29	1°11′	5.70	1°41′	8.11	2°11′	10.52	2°41′	12.93	3°11′	15.34	3°41′	17.75	4°11′	20.15	4°41′	22.56
0°12′	0.96	0°42′	3.37	1°12′	5.78	1°42′	8.19	2°12′	10.60	2°42′	13.01	3°12′	15.42	3°42′	17.83	4°12′	20.23	4°42′	22.64
0°13′	1.04	0°43′	3.45	1°13′	5.86	1°43′	8.27	2°13′	10.68	2°43′	13.09	3°13′	15.50	3°43′	17.91	4°13′	20.31	4°43′	22.72
0°14′	1.12	0°44′	3.53	1°14′	5.94	1°44′	8.35	2°14′	10.76	2°44′	13.17	3°14′	15.58	3°44′	17.99	4°14′	20.39	4°44′	22.80
0°15′	1.21	0°45′	3.62	1°15′	6.03	1°45′	8.44	2°15′	10.85	2°45′	13.26	3°15′	15.67	3°45′	18.07	4°15′	20.48	4°45′	22.88
0°16′	1.29	0°46′	3.70	1°16′	6.11	1°46′	8.52	2°16′	10.93	2°46′	13.34	3°16′	15.75	3°46′	18.15	4°16′	20.56	4°46′	22.96
0°17′	1.37	0°47′	3.78	1°17′	6.19	1°47′	8.60	2°17′	11.01	2°47′	13.42	3°17′	15.83	3°47′	18.23	4°17′	20.64	4°47′	23.04
0°18′	1.45	0°48′	3.86	1°18′	6.27	1°48′	8.68	2°18′	11.09	2°48′	13.50	3°18′	15.91	3°48′	18.31	4°18′	20.72	4°48′	23.12
0°19′	1.53	0°49′	3.94	1°19′	6.35	1°49′	8.76	2°19′	11.17	2°49′	13.58	3°19′	15.99	3°49′	18.39	4°19′	20.80	4°49′	23.20
0°20′	1.61	0°50′	4.02	1°20′	6.43	1°50′	8.84	2°20′	11.25	2°50′	13.66	3°20′	16.07	3°50′	18.47	4°20′	20.88	4°50′	23.28
0°21′	1.69	0°51′	4.10	1°21′	6.51	1°51′	8.92	2°21′	11.33	2°51′	13.74	3°21′	16.15	3°51′	18 55	4°21′	20.96	4°51′	23.36
0°22′	1.77	0°52′	4.18	1°22′	6.59	1°52′	9.00	2°22′	11.41	2°52′	13.82	3°22′	16.23	3°52′	18.63	4°22′	21.04	4°52′	23.44
0°23′	1.85	0°53′	4.26	1°23′	6.67	1°53′	9.08	2°23′	11.49	2°53′	13.90	3°23′	16.31	3°53′	18.71	4°23′	21.12	4°53′	23.52
0°24′	1.93	0°54′	4.34	1°24′	6.75	1°54′	9.16	2°24′	11.57	2°54′	13.98	3°24′	16.39	3°54′	18.79	4°24′	21.20	4°54′	23.60
0°25′	2.01	0°55′	4.42	1°25′	6.83	1°55′	9.24	2°25′	11.65	2°55′	14.06	3°25′	16.47	3°55′	18.87	4°25′	21.28	4°55′	23.68
0°26′	2.09	0°56′	4.50	1°26′	6.91	1°56′	9.32	2°26′	11.73	2°56′	14.14	3°26′	16.55	3°56′	18.95	4°26′	21.36	4°56′	23.76
0°27′	2.17	0°57′	4.58	1°27′	6.99	1°57′	9 40	2°27′	11.81	2°57′	14.22	3°27′	16.63	3°57′	19.03	4°27′	21.44	4°57′	23.84
0°28′	2.25	0°58′	4.66	1°28′	7.07	1°58′	9.48	2°28′	11.89	2°58′	14.30	3°28′	16.71	3°58′	19.11	4°28′	21.52	4°58′	23.92
0°29′	2.33	0°59′	4.74	1°29′	7.15	1°59′	9.56	2°29′	11.97	2°59′	14.38	3°29′	16.79	3°59′	19.19	4°29′	21.60	4°59′	24.00

$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR
5°00′	24.08	5°30′	26.49	6°00′	28.89	6°30′	31.30	7°00′	33.70	7°30′	36.11	8°00′	38.51	8°30′	40.91	9°00′	43.31	9°30′	45.71
5°01′	24.16	5°31′	26.57	6°01′	28.97	6°31′	31.38	7°01′	33.78	7°31′	36.19	8°01′	38.59	8°31′	40.99	9°01′	43.39	9°31′	45.79
5°02′	24.24	5°32′	26.65	6°02′	29.05	6°32′	31.46	7°02′	33.86	7°32′	36.27	8°02′	38.67	8°32′	41.07	9°02′	43.47	9°32′	45.87
5°03′	24.32	5°33′	26.73	6°03′	29.13	6°33′	31.54	7°03′	33.94	7°33′	36.35	8°03′	38.75	8°33′	41.15	9°03′	43.55	9°33′	45.95
5°04′	24.40	5°34′	26.81	6°04′	29.21	6°34′	31.62	7°04′	34.02	7°34′	36.43	8°04′	38.83	8°34′	41.23	9°04′	43.63	9°34′	46.03
5°05′	24.48	5°35′	26.89	6°05′	29.29	6°35′	31.70	7°05′	34.10	7°35′	36.51	8°05′	38.91	8°35′	41.31	9°05′	43.71	9°35′	46.11
5°06′	24.56	5°36′	26.97	6°06′	29.37	6°36′	31.78	7°06′	34.18	7°36′	36.59	8°06′	38.99	8°36′	41.39	9°06′	43.79	9°36′	46.19
5°07′	24.64	5°37′	27.05	6°07′	29.45	6°37′	31.86	7°07′	34.26	7°37′	36.67	8°07′	39.07	8°37′	41.47	9°07′	43.87	9°37′	46.27
5°08′	24.72	5°38′	27.13	6°08′	29.53	6°38′	31.94	7°08′	34.34	7°38′	36.75	8°08′	39.15	8°38′	41.55	9°08′	43.95	9°38′	46.35
5°09′	24.80	5°39′	27.21	6°09′	29.61	6°39′	32.02	7°09′	34.42	7°39′	36.83	8°09′	39.23	8°39′	41.63	9°09′	44.03	9°39′	46.43
5°10′	24.88	5°40′	27.29	6°10′	29.69	6°40′	32.10	17°0′	34.50	7°40′	36.91	8°10′	39.31	8°40′	41.71	9°10′	44.11	9°40′	46.51
5°11′	24.96	5°41′	27.37	6°11′	29.77	6°41′	32.18	7°11′	34.58	7°41′	36.99	8°11′	39.39	8°41′	41.79	9°11′	44.19	9°41′	46.59
5°12′	25.04	5°42′	27.45	6°12′	29.85	6°42′	32.26	7°12′	34.66	7°42′	37.07	8°12′	39.47	8°42′	41.87	9°12′	44.27	9°42′	46.67
5°13′	25.12	5°43′	27.53	6°13′	29.93	6°43′	32.34	7°13′	34.74	7°43′	37.15	8°13′	39.55	8°43′	41.95	9°13′	44.35	9°43′	46.75
5°14′	25.20	5°44′	27.61	6°14′	30.01	6°44′	32.42	7°14′	34.82	7°44′	37.23	8°14′	39.63	8°44′	42.03	9°14′	44.43	9°44′	46.83
5°15′	25.29	5°45′	27.69	6°15′	30.10	6°45′	32.50	7°15′	34.91	7°45′	37.31	8°15′	39.71	8°45′	42.11	9°15′	44.51	9°45′	46.91
5°16′	25.37	5°46′	27.77	6°16′	30.18	6°46′	32.58	7°16′	34.99	7°46′	37.39	8°16′	39.79	8°46′	42.19	9°16′	44.59	9°46′	46.99
5°17′	25.45	5°47′	27.85	6°17′	30.26	6°47′	32.66	7°17′	35.07	7°47′	37.47	8°17′	39.87	8°47′	42.27	9°17′	44.67	9°47′	47.07
5°18′	25.53	5°48′	27.93	6°18′	30.34	6°48′	32.74	7°18′	35.15	7°48′	37.55	8°18′	39.95	8°48′	42.35	9°18′	44.75	9°48′	47.15
5°19′	25.61	5°49′	28.01	6°19′	30.42	6°49′	32.82	7°19′	35.23	7°49′	37.63	8°19′	40.03	8°49′	42.43	9°19′	44.83	9°49′	47.23
5°20′	25.69	5°50′	28.09	6°20′	30.50	6°50′	32.90	7°20′	35.31	7°50′	37.71	8°20′	40.11	8°50′	42.51	9°20′	44.91	9°50′	47.31
5°21′	25.77	5°51′	28.17	6°21′	30.58	6°51′	32.98	7°21′	35.39	7°51′	37.79	8°21′	40.19	8°51′	42.59	9°21′	44.99	9°51′	47.39
5°22′	25.85	5°52′	28.25	6°22′	30.66	6°52′	33.06	7°22′	35.47	7°52′	37.87	8°22′	40.27	8°52′	42.67	9°22′	45.07	9°52′	47.47
5°23′	25.93	5°53′	28.33	6°23′	30.74	6°53′	33.14	7°23′	35.55	7°53′	37.95	8°23′	40.35	8°53′	42.75	9°23′	45.15	9°53′	47.55
5°24′	26.01	5°54′	28.41	6°24′	30.82	6°54′	33.22	7°24′	35.63	7°54′	38.03	8°24′	40.43	8°54′	42.83	9°24′	45.23	9°54′	47.63
5°25′	26.09	5°55′	28.49	6°25′	30.90	6°55′	33.30	7°25′	35.71	7°55′	38.11	8°25′	40.51	8°55′	42.91	9°25′	45.31	9°55′	47.71
5°26′	26.17	5°56′	28.57	6°26′	30.98	6°56′	33.38	7°26′	35.79	7°56′	38.19	8°26′	40.59	8°56′	42.99	9°26′	45.39	9°56′	47.79
5°27′	26.25	5°57′	28.65	6°27′	31.06	6°57′	33.46	2°27′	35.87	7°57′	38.27	8°27′	40.67	8°57′	43.07	9°27′	45.47	9°57′	47.87
5°28′	26.33	5°58′	28.73	6°28′	31.14	6°58′	33.54	7°28′	35.97	7°58′	38.35	8°28′	40.75	8°58′	43.15	9°28′	45.55	9°58′	47.95
5°29′	26.41	5°59′	28.81	6°29′	31.22	6°59′	33.62	7°29′	36.03	7°59′	38.43	8°29′	40.83	8°59′	43.23	9°29′	45.63	9°59′	48.03

Appendix 4 cont'd

$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR	$\Delta\beta$ $\Delta\gamma$	ΔR
10°00′	48.11	10°30′	50.50	11°00′	52.90	11°30′	55.30	12°00′	57.70	12°30′	60.10	13°00′	62.49	13°30′	64.86	14°00′	67.27
10°01′	48.19	10°31′	50.58	11°01′	52.98	11°31′	55.38	12°01′	57.78	12°31′	60.18	13°01′	62.57	13°31′	64.96	14°01′	67.35
10°02′	48.27	10°32′	50.66	11°02′	53.06	11°32′	55.46	12°02′	57.86	12°32′	60.26	13°02′	62.65	13°32′	65.04	14°02′	67.43
10°03′	48.35	10°33′	50.74	11°03′	53.14	11°33′	55.54	12°03′	57.94	12°33′	60.34	13°03′	62.73	13°33′	65.12	14°03′	67.51
10°04′	48.43	10°34′	50.82	11°04′	53.22	11°34′	55.62	12°04′	58.02	12°34′	60.42	13°04′	62.81	13°34′	65.20	14°04′	67.59
10°05′	48.51	10°35′	50.90	11°05′	53.30	11°35′	55.70	12°05′	58.10	12°35′	60.50	13°05′	62.89	13°35′	65.28	14°05′	67.67
10°06′	48.59	10°36′	50.98	11°06′	53.38	11°36′	55.78	12°06′	58.18	12°36′	60.58	13°06′	62.97	13°36′	65.36	14°06′	67.75
10°07′	48.67	10°37′	51.06	11°07′	53.46	11°37′	55.86	12°07′	58.26	12°37′	60.66	13°07′	63.05	13°37′	65.44	14°07′	67.83
10°08′	48.75	10°38′	51.14	11°08′	53.54	11°38′	55.94	12°08′	58.34	12°38′	60.74	13°08′	63.13	13°38′	65.52	14°08′	67.91
10°09′	48.83	10°39′	51.22	11°09′	53.62	11°39′	56.02	12°09′	58.42	12°39′	60.82	13°09′	63.21	13°39′	65.60	14 09′	67.99
10°10′	48.91	10°40′	51.30	11°10′	53.70	11°40′	56.10	12°10′	58.50	12°40′	60.90	13°10′	63.29	13°40′	65.68	14°10′	68.07
10°11′	48.99	10°41′	51.38	11°11′	53.78	11°41′	56.18	12°11′	58.58	12°41′	60.98	13°11′	63.37	13°41′	65.76	14°11′	68.15
10°12′	49.07	10°42′	51.46	11°12′	53.86	11°42′	56.26	12°12′	58.66	12°42′	61.06	13°12′	63.45	13°42′	65.84	14°12′	68.23
10°13′	49.15	10°43′	51.54	11°13′	53.94	11°43′	56.34	12°13′	58.74	12°43′	61.14	13°13′	63.53	13°43′	66.92	14°13′	68.31
10°14′	49.23	10°44′	51.62	11°14′	54.02	11°44′	56.42	12°14′	58.82	12°44′	61.22	13°14′	63.61	13°44′	66.00	14°14′	68.39
10°15′	49.30	10°45′	51.70	11°15′	54.10	11°45′	56.50	12°15′	58.90	12°45′	61.29	13°15′	63.68	13°45′	66.07	14°15′	68.46
10°16′	49.38	10°46′	51.78	11°16′	54.18	11°46′	56.58	12°16′	58.98	12°46′	61.37	13°16′	63.76	13°46′	66.15	14°16′	68.54
10°17′	49.46	10°47′	51.86	11°17′	54.20	11°47′	56.65	12°17′	59.06	12°47′	61.45	13°17′	63.84	13°47′	66.23	14°17′	68.62
10°18′	49.54	10°48′	51.94	11°18′	54.34	11°48′	56.74	12°18′	59.14	12°48′	61.53	13°18′	63.92	13°48′	66.31	14°18′	68.70
10°19′	49.62	10°49′	52.02	11°19′	54.42	11°49′	56.82	12°19′	59.22	12°49′	61.61	13°19′	64.00	13°49′	66.39	14°19′	68.78
10°20′	49.70	10°50′	52.10	11°20′	54.50	11°50′	56.90	12°20′	59.30	12°50′	61.69	13°20′	64.08	13°50′	66.47	14°20′	68.86
10°21′	49.78	10°51′	52.18	11°21′	54.58	11°51′	56.98	12°21′	59.38	12°51′	61.77	13°21′	64.16	13°51′	66.55	14°21′	68.94
10°22′	49.86	10°52′	52.25	11°22′	54.66	11°52′	57.06	12°22′	59.46	12°52′	61.85	13°22′	64.24	13 52′	66.63	14°22′	69.02
10°23′	49.94	10°53′	52.34	11°23′	54.74	11°53′	57.14	12°23′	59.54	12°53′	61.93	13°23′	64.32	13°53′	66.71	14°23′	69.10
10°24′	50.02	10°54′	52.42	11°24′	54.82	11°54′	57.22	12°24′	59.62	12°54′	62.01	13°24′	64.40	13°54′	66.79	14°24′	69.18
10°25′	50.10	10°55′	52.50	11°25′	54.90	11°55′	57.30	12°25′	59.70	12°55′	62.09	13°25′	64.48	13 55′	66.87	14°25′	69.26
10°26′	50.18	10°56′	52.58	11°26′	54.98	11°56′	57.38	12°26′	59.78	12°56′	62.17	13°26′	64.56	13°56′	66.95	14°26′	69.34
10°27′	50.26	10°57′	52.66	11°27′	55.06	11°57′	67.46	12°27′	59.86	12°57′	62.25	13°27′	64.64	13°57′	67.03	14°27′	69.42
10°28′	50.34	10°58′	52.74	11°28′	55.14	11°58′	57.54	12°28′	59.94	12°58′	62.33	13°28′	64.72	13°58′	67.11	14°28′	69.50
10°29′	50.42	10°59′	52.82	11°29′	55.22	11°59′	57.62	12°29′	60.02	12°59′	62.41	13°29′	64.80	13°59′	67.19	14°29′	69.58

Note: When $\Delta\beta$ or $\Delta\gamma$ is negative, ΔR should likewise be taken as negative.

APPENDIX 5

Table of thread-cutting conditions

Thread diameter, D	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.7	0.9	1 mm
Thread pitch	0.075	0.075	0.10	0.10	0.125	0.125	0.150	0.175	0.225	0.250
Cutting speed v for taps in LS63-3 brass	2	2.5	3	3.5	4	4.5	5	6	7	9.5
Cutting speed v for chasers in U7AV steel	4.2	4.8	5.5	6	7	7.5	8.5	9.8	11.5	14

APPENDIX 6

Table of basic times for lapping metallic parts on the S-15 machine.

Allowance 0.02 mm. Surface-finish quality, class 9—10

No. of parts machined simult'ly	Diameter of machined part	1	1.5	2	2.5	3	4	5	6	8	10
		Basic lapping time, minutes									
20		—	—	—	—	0.42	0.62	0.85	1.05	1.55	2.00
25		—	—	—	0.38	0.48	0.70	0.95	1.20	1.70	2.30
30		—	—	—	0.44	0.55	0.80	1.05	1.35	1.90	2.6
35		—	—	—	0.48	0.60	0.90	1.15	1.5	2.15	2.9
40		—	—	0.38	0.55	0.65	1.00	1.30	1.65	2.40	3.2
50		—	0.30	0.44	0.60	0.75	1.10	1.50	1.9	2.70	3.7
60		0.2	0.34	0.5	0.65	0.85	1.25	1.7	2.15	3.1	4.1
70		0.22	0.38	0.55	0.75	0.95	1.40	1.9	2.4	3.5	4.5
80		0.24	0.40	0.6	0.85	1.05	1.55	2.1	2.65	3.9	5.0
100		0.27	0.47	0.70	0.95	1.20	1.75	2.40	3.00	4.4	5.8
120		0.30	0.54	0.80	1.05	1.35	2.0	2.7	3.4	5.0	6.6
150		0.35	0.62	0.92	1.20	1.5	2.3	3.1	3.9	5.7	7.6
180		0.40	0.70	1.03	1.35	1.7	2.6	3.5	4.4	6.5	8.6
200		0.45	0.80	1.15	1.5	1.9	2.9	3.9	4.9	7.3	—
250		0.50	0.90	0.30	1.7	2.2	3.2	4.3	5.5	8.1	—

APPENDIX 7

Table of polishing times for pinion teeth

Allowance, mm	Module m, mm	Number of pinion teeth, z								
		6	7	8	10	12	14	16	18	20
		Polishing (basic) time T_p, min								
0.005	0.08	0.017	0.019	0.021	0.024	0.027	0.031	0.034	0.037	0.040
	0.10	0.019	0.021	0.023	0.027	0.030	0.034	0.037	0.041	0.044
	0.12	0.02	0.023	0.025	0.029	0.032	0.037	0.040	0.044	0.047
	0.14	0.022	0.024	0.027	0.031	0.035	0.039	0.043	0.047	0.051
	0.16	0.023	0.026	0.028	0.033	0.037	0.041	0.046	0.049	0.054
	0.18	0.024	0.027	0.029	0.034	0.039	0.043	0.048	0.052	0.056
	0.20	0.025	0.028	0.031	0.036	0.040	0.045	0.050	0.054	0.059
	0.25	0.028	0.031	0.034	0.039	0.044	0.050	0.055	0.060	0.064
	0.30	0.03	0.033	0.036	0.043	0.048	0.054	0.058	0.064	0.070
0.01	0.08	0.024	0.027	0.030	0.035	0.039	0.044	0.048	0.052	0.057
	0.10	0.27	0.030	0.032	0.038	0.042	0.048	0.053	0.057	0.062
	0.12	0.029	0.032	0.035	0.041	0.046	0.052	0.057	0.062	0.067
	0.14	0.031	0.034	0.038	0.044	0.049	0.055	0.061	0.066	0.072
	0.16	0.032	0.036	0.040	0.046	0.052	0.059	0.064	0.070	0.076
	0.18	0.034	0.038	0.042	0.049	0.054	0.061	0.067	0.074	0.080
	0.20	0.036	0.040	0.044	0.051	0.057	0.064	0.071	0.077	0.083
	0.25	0.039	0.044	0.048	0.056	0.062	0.071	0.078	0.085	0.091
	0.30	0.042	0.047	0.052	0.060	0.067	0.076	0.084	0.091	0.096

APPENDIX 8

Table of polishing (basic) times for journals and shoulders machined on the S-8a machine.

Allowance on the diameter = 0.01 mm

Dia. of machined surface, mm	Length of the surface machined										
	< 0.7	0.8	1.0	1.2	1.6	2.0	2.6	3.0	3.5	4.0	5.0
	Polishing (basic) time, T_p, min										
0.2	0.016	0.017	0.019	0.021	0.024	0.028	—	—	—	—	—
0.3	0.017	0.019	0.022	0.025	0.027	0.033	0.038	0.042	—	—	—
0.5	0.021	0.028	0.027	0.029	0.034	0.04	0.046	0.051	0.056	—	—
0.8	0.026	0.027	0.031	0.035	0.040	0.047	0.054	0.061	0.067	0.073	0.082
1.0	0.028	0.029	0.034	0.038	0.043	0.052	0.059	0.065	0.072	0.078	0.085
1.5	0.031	0.034	0.038	0.043	0.049	0.059	0.067	0.075	0.082	0.089	0.103
2.0	0.035	0.038	0.043	0.048	0.054	0.064	0.074	0.083	0.092	0.100	0.110
3.0	0.040	0.043	0.049	0.055	0.064	0.075	0.085	0.096	0.107	0.115	0.129

APPENDIX 9

N-3418 standard for washing watch parts and blanks

Operation	Working material and composition of washing solution	Holding time, min	Temperature, °C
Chip removal			
Three consecutive gasoline washes	"Galosha" GOST 443-41 gasoline	0.5–1	15–18
Drying in sawdust	Beech or palm sawdust		
Blowing off with pure cool air	Pure air from a compressor		18–24
Hot-air drying			

EXPLANATORY LIST OF ABBREVIATED NAMES OF U.S.S.R. INSTITUTIONS, ORGANIZATIONS, ETC. APPEARING IN THIS TEXT

Abbreviation	Full name (transliterated)	Translation
ChMTU	Chernaya Metallurgiya. Tekhnicheskie Usloviya	Technical Specifications for the Ferrous Metallurgy
Glavchasprom	Glavnoe Upravlenie Chasovoi Promyshlennosti	Main Administration of the Watchmaking Industry
GOST	Gosudarstvennyi Obshchesoyuznyi Standart	All-Union Government Standard
MKhP	Ministerstvo Khimicheskoi Promyshlennosti	Ministry of the Chemical Industry
MMiP	Ministerstvo Mashinostroeniya i Priborostroeniya	Ministry of the Machine-Building and Instrument-making Industry
MPTU	Metallurgicheskaya Promyshlennost'. Tekhnicheskie Usloviya	Technical Specifications for the Metallurgical Industry
NIIChasProm	Nauchno-Issledovatel'skii Institut Chasovoi Promyshlennosti	Scientific Research Institute of the Watchmaking Industry
Orgavtoprom	Kontora po Organizatsii Stroitel'stva Predpriyatii Avtomobil'noi Promyshlennosti	Office for the Planning of Construction of Plants for the Automotive Industry
Orgmashpribor	Kontora po Organizatsii Stroitel'stva Predpriyatii Mashinostroitel'noi i Priborostroitel'noi Promyshlennosti	Office for the Planning of Construction of Plants for the Machine-Building and Instrument-Making Industry
OST	Obshchesoyuznyi Standart	All-Union Standard

Abbreviation	Full name (transliterated)	Translation
TsMTU(TUTsMo)	Tsvetnaya Metallurgiya. Tekhnicheskie Usloviya	Technical Specifications for the Nonferrous Metallurgy
TU	Tekhnicheskie Usloviya	Technical Specifications
TUKhP	Tekhnicheskie Usloviya Khimicheskoi Promyshlennosti	Technical Specifications for the Chemical Industry
VNIITOMASh	Vsesoyuznoe Nauchnoe Inzhenerno-Tekhnicheskoe Obshchestvo Mashinostroitelei	All-Union Scientific Technical Society of Mechanical Engineers
VTU	Vremennye Tekhnicheskie Usloviya	Provisional Technical Specifications

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