

Ministry of Education and Science of Ukraine  
Ternopil National Technical University named after I. Puluj  
Department of Mechanical Engineering Technology

**ЛІТЕРАТУРА**



**НАВЧАЛЬНО-МЕТОДИЧНА**

Methodical instructions for performing practical work on the  
subject "Operation and maintenance of machines"  
for students of all forms of study  
Direction of preparation 131 " Applied mechanics"

Ternopil

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Ministry of Education and Science of Ukraine  
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Mechanical Engineering  
department

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Direction of preparation 131 " Applied mechanics

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## DETERMINATION OF THE LENGTH OF REPAIR CYCLES AND REPAIR PERIODS OF EQUIPMENT OF THE MACHINE-BUILDING ENTERPRISE

Objective: To learn how to practically determine the duration of repair cycles and inter-repair periods of equipment.

Brief theoretical information

Repair cycle of equipment ( $L_p$ ) - is a recurring set of different types of scheduled repairs performed in a predictable sequence due to the establishment of an equal number of hours of operational time of equipment, called the inter-repair period.

Structure of the repair cycle ( $C_{up}$ ) – is a list of repairs that are part of the repair cycle, placed in a sequence of their execution.

For example: a structure consisting of one capital, one medium and four current repairs, is written as follows:

KP – ПП – ПП – CP – ПП – ПП – KP

Duration of repair cycle ( $T_{up}$ ) – is the number of hours of operating time of the equipment during which all repairs that are part of the cycle are performed.

Simple equipment related to the implementation of planned and unplanned repairs, as well as maintenance in the duration of the repair cycle are not included.

KP – ПП1 – ПП2 – CP – ПП3 – ПП4 – KP

Empirical formulas for the duration of repair cycles are a product of a constant for each type of equipment of the factor of coefficients that have variables:

For metal cutting equipment:

$$T_{up} = 16800 \times K_{om} \times K_{mi} \times K_{mo} \times K_{km} \times K_{\epsilon} \times K_{\delta}, \text{ h.}$$

For press-forging equipment:

$$T_{up} = 10000 \times K_{po} \times K_{\epsilon} \times K_{\delta}, \text{ h.}$$

For foundry equipment:

$$T_{up} = 6000 \times \kappa_{po} \times \kappa_{\theta} \times \kappa_{\partial}, \text{ h,}$$

where  $\kappa_{OM}$  – coefficient of the material being processed;

$\kappa_{Mi}$  – the coefficient of the applied instrument;

$\kappa_{mo}$  – the coefficient of the class of equipment accuracy;

$\kappa_{KM}$  – coefficient of mass category;

$\kappa_{\theta}$  – coefficient of age;

$\kappa_{\partial}$  – coefficient of durability;

$\kappa_{po}$  – coefficient of repair features.

Inter-repair period ( $T_{mp}$ ) – is the period of operating time between two consecutive planned repairs:

$$T_{mp} = \frac{T_{up}}{n_c + n_n + 1},$$

where  $n_c$  - number of average repairs;

$n_n$  - number of current repairs.

Value of coefficients  
Metal cutting equipment

Coefficient	Parameter	The value of the coefficient
$\kappa_{OM}$	Structural steel	1,0
	Other	0,75
$\kappa_{Mi}$	Metal	1,0
	Abrasive	0,8
$\kappa_{mo}$	H	1,0
	II	1,5
	B, A, C	2,0
$\kappa_{KM}$	Up to 10 tons	1,0
	More 10 up to 100 tons	1,35
	More 100 tons	1,7

Age coefficient  $\kappa_a$ 

Age	Accuracy class	Order number of repair cycle	The value of the coefficient
Up to 10 years old	H, П	1st and 2nd	1,0
	B, A, C	1 st	
More than 10 years	H	2nd and 3rd	0,9
	П, B, A, C	2nd	
	H	4th	0,8
	П, B, A, C	3rd	
H	5th and more	0,7	
П, B, A, C	4th and more		

Durability factor  $\kappa_d$ 

Year of equipment manufacture	The value of the coefficient
To 2005	0,8
From 2006 to 2010	0,9
From 2011	1,0

## Forging and pressing equipment

Age coefficient  $\kappa_a$ 

Order number of repair cycle	The value of the coefficient
1-й	1,0
2-й	0,9
3-й	0,8

Longevity coefficient  $\kappa_d$ 

Year of equipment manufacture	The value of the coefficient
To 1990	0,5
From 1991 to 1995	0,6
From 1996 to 2000	0,7
From 2001 to 2010	1,0
After 2011	1,2

Coefficient of repair features  $\kappa_{po}$ 

$$\kappa_{po} = 0,3 \dots 3,0$$

## Progress

1. From the passport of the machine, named as a teacher, or according to the variant (appendix A.1), to write out its purpose, specifications and year of manufacture.

2. Determine the values of the coefficients included in the empirical formulas explaining the choice.

3. Determine the duration of the repair cycle and repair period for the three species structure.

### Contents of the report

1. Technical characteristics and year of manufacturing of the machine tool.
2. The values of the coefficients included in the empirical formulas justifying the choice.
3. Duration of repair cycle and inter-repair period for three species structure.

### Annex A

#### A.1 - Characteristics of machine tools

Variant	Model	Year of manufacture	Order number of repair cycle	Variant	Model	Year of manufacture	Order number of repair cycle
1	1E110Π	2001	5th	15	3Y10B	1995	2nd
2	1E125	2002	5th	16	3M150	1996	2nd
3	1E165Π	2003	5th	17	3M163B	1997	1st
4	11Φ40	2004	4th	18	3M197	1998	1st
5	1103A	2005	4th	19	6B75B	1999	1st
6	1B10B	2006	4th	20	675Π	2000	1st
7	1M10A	2007	3rd	21	6P80	2001	5th
8	2H106Π	2008	3rd	22	6P83	2002	5th
9	2H135	2009	3rd	23	6606	2003	5th
10	2H150	2010	3rd	24	7112	2004	4th
11	2E440A	2011	2nd	25	7228	2005	4th
12	2M615	2012	2nd	26	7A311	2006	4th
13	2636Φ1	2010	2nd	27	7M36	2007	3rd
14	2E78Π	2011	2nd	28	7B58	2008	3rd



## DETERMINING THE CONJUGATION RESOURCE

Aim: To learn how to determine the wear rate, the conjugation resource and the boundary of the dispersion of parameters.

Students receive data for calculations as a result of measurements of conjugation details and technical documentation, or choose from applications according to the individual number of the book.

For the first two digits of the individual number of the reference book in Appendix A.2, choose the confidence probability and inter-repair work of the conjugations, in the last, in Appendix B, the name of the conjugate, the size according to the drawing and the data of the micrometer. Students of correspondence form of study when choosing the number of the assignment to the first digit of the individual number of the book add a unit.

For example: a student, whose graduation book has the number MT-95-027, from Appendix A.2, Option 02, chooses the confidence probability and rehabilitation of the conjugations, and from Appendix B, option 7, the names of the conjugations, the sizes according to the drawing and the data of the micrometers. The student of the correspondence form of study, whose score book has the number of MTZ-95-027, from Appendix A.2, option 12, chooses the confidence probability and inter-repair work of conjugations, and from Appendix B, option 7, the names of the conjugations, the dimensions according to the drawing and micrometers.

### Contents of the report

Determine all the necessary indicators for the variant with the conditional number of the student's student book - 0610. Output conditions have the following meanings: inter-repair work conjugation  $T_{mp} = 2000$  h; confidence limits  $a = 0,8$ ; coefficient of variation  $n = 0,36$ . We put them in the table.

Table 2.1 - Output data on specifications and conjugate measurements

Variant task	The name of the conjugation details	Dimensions according to the drawing, mm	Tension (-)clearance (+)			Data of measurements	
			normal, mm	permissible, mm	limit, mm	size at the place of wear, mm	Work on measurements
10	Sleeve		0,022	0,11	0,25	42,15	2010
	Finger		0,047			42,16	2070
						42,17	2130

For practical purposes, the residual and full resources of conjugation are often determined without micrometer measurements. The amount of wear in the period of tinting is not taken into account.

The wear rate is determined by the formula

$$V_c = \frac{S_{zp} - S_\delta}{T_{mp}},$$

where  $S_{zp}$  – marginal clearance in conjugation, mm;

$S_\delta$  – allowable clearance, mm;

$T_{mp}$  – inter-repair resource, h.

$$V_c = \frac{0,25 - 0,11}{2000} = 7 \cdot 10^{-5} \text{ mm / h}$$

The average full resource is determined from the dependence:

$$T_{cn} = \frac{S_{zp} - S_{n.max}}{V_c},$$

$$T_{cn} = \frac{0,25 - 0,047}{7 \cdot 10^{-5}} = 2900 \text{ h.}$$

where  $S_{n.max}$  - normal (initial) maximum clearance in conjugation mm.

For a maximum maximum clearance in conjugation, take the maximum gap after spinning the conjugation. In most cases, the size of the gap after spin does not exceed the magnitude of the tolerances for their manufacturing.

Therefore, the initial maximum gap is equal to

$$S_{H \max} = D_{\max} - d_{\min} = 42,038 - 41,991 = 0,047 \text{ mm},$$

$$\text{or } S_{H \max} = DD_{\max} - Dd_{\min} = 0,038 + 0,009 = 0,047 \text{ mm},$$

where  $D_{\max}$  – upper limit of the hole, mm;

$d_{\min}$  – lower limiting size of the shaft, mm.

$$D_{\max} = D + DD_{\max} = 42 + 0,038 = 42,038 \text{ mm},$$

$$d_{\min} = d + Dd_{\min} = 42 - 0,009 = 41,991 \text{ mm},$$

where  $D$  and  $d$  - nominal dimensions of the hole and shaft, mm;

$DD_{\max}$  - maximum (upper) tolerance of hole mm;

$Dd_{\min}$  - minimum (lower) tolerance of the shaft, mm.

With the method of individual forecasting, the confidence limits of the scattering of the full and the residual resource are determined by the so-called quantum. The scattering of resources of the same name conjugates most often obeys the Weibull-Gnidenko distribution law.

Trust boundaries of the full resource are:

- нижня

$$T_{\text{ниж}} = \frac{H_K}{\alpha} (\alpha_n)^n \frac{T_{\text{сн}}}{C_\varepsilon} + T_{\text{зм}},$$

$$T_{\text{верх}} = \frac{H_K}{\alpha} (\alpha_e)^n \frac{T_{\text{сн}}}{C_\varepsilon} + T_{\text{зм}},$$

- верхня

where  $H_K/a$  - is the Weibull-Gnidenko distribution quantum, (Appendix B.2);

$\alpha_n$  і  $\alpha_e$  - confidence probability for the lower and upper bounds;

$n$  - coefficient of variation;

$C_\varepsilon$  - table coefficient (Annex B.1);

$T_{\text{зм}}$  - magnitude of the displacement of the beginning of the dispersion of the resource, h.

Determine the confidence probability for the lower and upper bounds

$$\alpha_n = (1 - \alpha)/2 = (1 - 0,8)/2 = 0,1;$$

$$\alpha_e = \alpha_n + \alpha = 0,1 + 0,8 = 0,9.$$

Using the application B1 for a known coefficient of variation  $n = 0,36$  we find the coefficients  $C_\sigma = 0,322$  and  $\sigma = 3,03$ . Then, using Appendix B.2, known  $a_H$  and  $a_\sigma$  quantum

$$\frac{H_K}{\alpha}(\alpha_n) = 0,472 \text{ i } \frac{H_K}{\alpha}(\alpha_\sigma) = 1,32.$$

The magnitude of the initial displacement of the dispersion of the resource

$$T_{3M} \approx 0,3 T_{cn} = 0,3 \cdot 2900 = 870 \text{ h.}$$

Determine the confidence limits of the full resource

$$T_{nx} = 0,472 \frac{0,36 \cdot 2900}{0,322} + 870 = 2400$$

$$T_{ne} = 1,32 \frac{0,36 \cdot 2900}{0,322} + 870 = 5150 \text{ h}$$

Residual resource conjugation is determined from the expression

$$T_{c3} = T_{cn} - T_\sigma$$

where  $T_\sigma$  – time to measurements, hours.

$$T_{c3} = 2900 - 2010 = 890$$

The lower and upper limits of dispersion of the residual resource for practical calculations can be defined as follows

$$T_{3H} = 0,7 \cdot T_{c3} = 0,7 \cdot 890 = 623$$

$$T_{3\sigma} = 1,35 \cdot T_{c3} = 1,35 \cdot 890 = 1202 \text{ h.}$$

Dimensions of conjugation details in the process of work are determined based on their initial dimensions and size of wear. With the method of individual forecasting, the wear of a measuring part is determined from the expression:

$$\text{for the shaft} \quad U_{3H\sigma} = d_{\min} - d_{\text{вум}},$$

$$\text{for the hole} \quad U_{3HO} = D_{\text{вум}} - D_{\max},$$

where  $d_{\text{вум}}$  and  $D_{\text{вум}}$  – measured diameter of the shaft and hole respectively, mm.

In order to determine to which of the details related measurements, it is necessary to know that with increasing production, the size of the shaft decreases, and the hole - increases. In our case, the hole is measured

$$U_{\text{ЗНО}} = D_{\text{ДУМ}} - D_{\text{max}} = 42,15 - 42,038 = 0,112 \text{ mm}$$

Extreme wear of the conjugation details is determined from the expression

$$U_{\text{зп}} = \frac{S_{\text{зп}} - S_{\text{н max}}}{V_c} \cdot V_{\delta},$$

where  $V_{\delta}$  – the wear rate of the parts, mm / h.

The wear rate of the measured part is equal

$$V_{\delta} = \frac{U_{\text{ДУМ}}}{T_{\epsilon}}$$

$$V_{\delta 1} = \frac{U_{\text{ЗНО}}}{T_{\epsilon}} = \frac{0,112}{2010} = 5,6 \cdot 10^{-5}$$

The speed of wearing the understated parts is found in the expression

$$V_{\delta 2} = V_c - V_{\delta 1} = 7 \cdot 10^{-5} - 5,6 \cdot 10^{-5} = 1,4 \cdot 10^{-5}$$

Determine the limiting wear of the parts of the conjugation

$$U_{\text{зпо}} = \frac{0,25 - 0,047}{7 \cdot 10^{-5}} \cdot 5,6 \cdot 10^{-5} = 0,162$$

$$U_{\text{зпе}} = \frac{0,25 - 0,047}{7 \cdot 10^{-5}} \cdot 1,4 \cdot 10^{-5} = 0,041 \text{ mm}$$

Acceptable in case of repair, wear parts we find from the expression

$$U_{\delta \text{п}} = U_{\text{зп}} - T_{\text{мр}} \cdot V_{\delta}$$

for the hole  $U_{\delta \text{по}} = 0,162 - 2000 \cdot 5,6 \cdot 10^{-5} = 0,05 \text{ mm}$ ,

for the shaft  $U_{\delta \text{пе}} = 0,041 - 2000 \cdot 1,4 \cdot 10^{-5} = 0,013 \text{ mm}$ .

Based on the data we build the scheme (Figure 2.1) in such a sequence.  
From the point 0 on the scale upward postpone the value of the upper boundary deviation of the aperture  $DD_{\text{max}}$ , and in the bottom - lower boundary deflection of the shaft  $Dd_{\text{min}}$  and receive respectively points 1 and 2. Through them, there are

horizontal lines between which the size  $S_{Hmax}$ . On the abscissa we put point 3, which corresponds to the average total resource of conjugation, and we carry through it the vertical line, which upwards from point 3, set aside  $DD_{max} + U_{zpo}$ , getting point 4, and down – value  $d_{min} + U_{zpb}$ , receiving point 5. Points 1 and 4, as well as points 2 and 5 interconnect straight lines. Line 1 - 4 characterizes the process of wear of the hole, and line 2 - 5 characterizes the process of wear of the shaft, depending on the work. All other values of working time, size, wear and clearance are placed in accordance with Fig. 2.1, indicating numerical values.

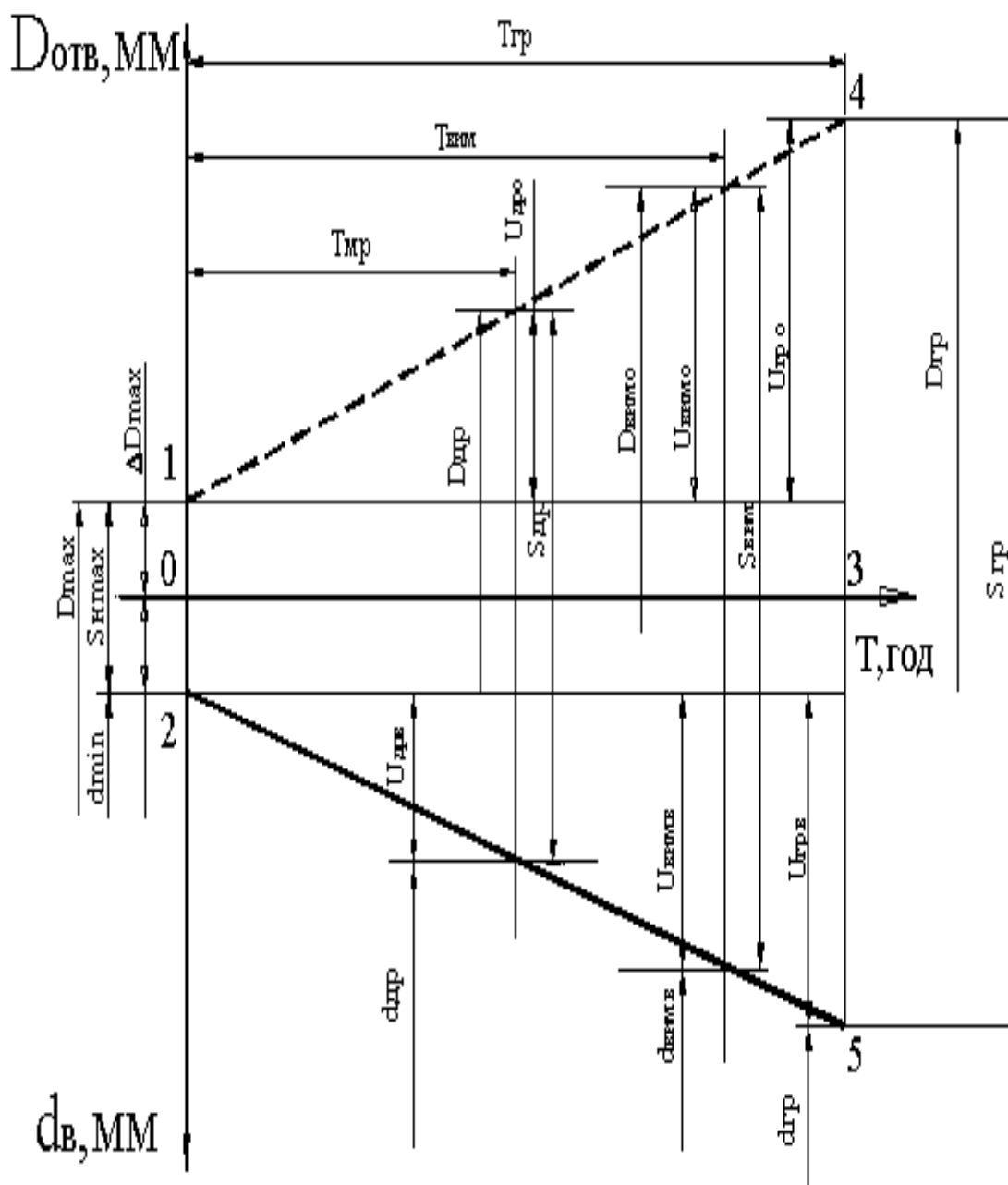


Figure 2.1 - Scheme for determining the resources and dimensions of the conjugation details

### Annex A

#### A.2 - rust probability a, inter-repair workout of conjugations $T_{mp}$ , and coefficient of variation n

Options	$T_{mp}$ , h.	a	n	Options	$T_{mp}$ , h.	a	n
00	1900	0,70	0,30	15	1900	0,85	0,45
01	2000	0,75	0,31	16	2000	0,70	0,46
02	2100	0,80	0,32	17	2100	0,75	0,47
03	2000	0,85	0,33	18	2000	0,80	0,48
04	2100	0,70	0,34	19	2100	0,85	0,49
05	1900	0,75	0,35	20	1900	0,70	0,50
06	2000	0,80	0,36	21	1900	0,75	0,51
07	2100	0,85	0,37	22	2100	0,80	0,37
08	2000	0,65	0,38	23	1900	0,85	0,36
09	2100	0,60	0,39	24	2100	0,70	0,35
10	1900	0,65	0,40	25	1900	0,75	0,34
11	2000	0,70	0,41	26	2000	0,80	0,33
12	2100	0,75	0,42	27	2100	0,85	0,32
13	2000	0,80	0,43	28	2000	0,70	0,31
14	1900	0,85	0,44	29	1900	0,65	0,30

### Annex B

#### Examples of output data from TU and conjugate measurements

Options	The name of the conjugation details	Dimensions according to the drawing, mm	Tension (-)clearance (+)			Data of measurements	
			normal, mm	permissible, mm	limit, mm	size at the place of wear., mm	working out to measurements
0	Lever		0,000	0,40	0,50	6,14	2010
	Finger		0,200			6,16	2070
						6,18	2130
1	Satellite		0,020	0,60	0,80	25,70	2160
						25,68	2220
	Bushing		0,330			25,66	2280

2	Bearing					49,99	1310
	Shaft		-0,020	0,05	0,10	49,98	1370
						49,97	1430
3	Bushing		0,040			25,05	2460
	Platen		0,115	0,20	0,25	25,07 25,09	2520 2580
4	Corps		0,05			154,05	1610
	Glass		0,140	0,25	0,30	154,08 154,11	1670 1730
5	Corps		0,018			164,91	2800
	Bushing		0,085	0,20	0,25	164,90 164,89	2860 2920
6	Balancer		0,032			49,90	2160
	Axis		0,150	0,20	0,30	49,89 49,88	2220 2280
7	Bushing		0,340			50,6	1310
	Axis		0,550	0,60	2,5	50,8 51,0	1370 1430
8	Bush		0,200			70,45	1460
	Capa		0,520	0,60	2,00	70,65 70,85	1520 1580
9	Gear		0,036			86,90	1220
	Glass		0,290	0,25	0,60	86,88 86,86	1300 1380
10	Bushing		0,022			42,15	2010
	Finger		0,047	0,11	0,25	42,16 42,17	2070 2130

## Annex B

## B.1 - Parameters and coefficients of the Weibull distribution law

$b$	$k_b$	$C_b$	$v$	$b$	$k_b$	$C_b$	$v$
3,71	0,902	0,271	0,30	2,61	0,888	0,365	0,41
3,58	0,901	0,279	0,31	2,55	0,888	0,372	0,42
3,46	0,899	0,287	0,32	2,48	0,887	0,382	0,43
3,34	0,898	0,296	0,33	2,42	0,887	0,391	0,44
3,23	0,896	0,305	0,34	2,36	0,886	0,399	0,45
3,13	0,896	0,305	0,35	2,30	0,886	0,408	0,46



3,03	0,893	0,322	0,36	2,25	0,886	0,416	0,47
2,94	0,892	0,330	0,37	2,20	0,886	0,425	0,48
2,86	0,891	0,338	0,38	2,15	0,886	0,432	0,49
2,78	0,890	0,346	0,39	2,10	0,886	0,443	0,50
2,70	0,889	0,355	0,40	2,06	0,886	0,451	0,51

$\frac{H_x}{\alpha}$   
B.2 – Quantum  $\alpha$  division of the law of Weibull

<i>b</i>	<i>F(t)</i>								
	<b>0,07</b>	<b>0,10</b>	<b>0,15</b>	<b>0,20</b>	...	<b>0,70</b>	<b>0,80</b>	<b>0,90</b>	<b>0,93</b>
<b>1,6</b>	0,194	0,245	0,332	0,392	...	1,12	1,35	1,68	1,84
<b>1,8</b>	0,233	0,286	0,380	0,435	...	1,11	1,30	1,59	1,72
<b>2,0</b>	0,269	0,325	0,419	0,472	...	1,10	1,27	1,52	1,63
<b>2,5</b>	0,350	0,407	0,498	0,549	...	1,08	1,21	1,40	1,48
<b>3,0</b>	0,417	0,472	0,558	0,607	...	1,06	1,17	1,32	1,39

## DETERMINATION OF THE CRITERIA FOR THE STABILITY OF THE TECHNOLOGICAL PROCESS AND ENSURING THE ACCURACY OF MACHINING ON THE LATHE THROUGH RATIONAL TUNING

Aim: To learn to practically define the criteria for the stability of the technological process.

When machining parts on universal machine tools, the error of tuning  $\Delta_x$  and error of instantaneous scattering prevail over the single-dimensional size method  $\Delta_{pm}$ .

The processing error is then determined by the formula

$$\Delta_\delta = \sqrt{\Delta_x + \Delta_{pm}}.$$

Ideally, the processing center error grouping center coincides with the center of the tolerance field to the size.

If the processing tolerance is greater than the processing error  $\delta > \Delta_\delta$ , then the reliability of accuracy will be guaranteed, if on the contrary  $\delta < \Delta_\delta$  about reliability will be less than one.

Resource of accuracy  $K_A$  systems are determined by the formula

$$K_A = \frac{\delta}{\Delta_\delta},$$

when  $K_A > 1$  - there is a reserve of accuracy, and at  $K_A < 1$  reliability of accuracy is low.

The adjustment error consists of errors in the installation of the instrument on the size and error of measuring the dimensions of the part at the test passages.

The dispersion error depends on the changes in the allowances, the hardness of the workpieces, the state of the tool, the warping of parts, vibrations, etc.

To reduce the configuration error, you need to control the constancy of the level of the rational setting, choose the measuring instrument correctly, apply devices that increase the accuracy of the tool set to the size.

The error of instantaneous dispersion can be reduced by rational construction of the structure of the technological process, the choice of the optimal number of transitions and cutting modes, improving the quality of sharpening the instrument, introducing into the technological process the procurement of the required types of heat treatment for reduction of internal stresses and warping.

The statistical analysis of the accuracy of the processing makes it possible to quantify the stability of the technological process. For universal machine tools working on the basis of the single-dimensional method of obtaining sizes and adjusting the test passages, the dispersion of errors is characteristic, which corresponds to the law of normal distribution.

The preparation of conditional parts is possible in the case where the field of scattering of component errors  $\Delta_{\sigma}$  does not exceed the processing tolerance,  $\delta$ , and the accuracy resource is equal to or greater than one. This is the first criterion for the stability of the technological process.

$$K_{\Delta} \geq 1$$

In real conditions, the center of grouping of the size of parts, depending on the level of adjustment does not coincide with the rational level, which is located in the middle of the field of admission, according to the drawing of the detail, and the displacement relative to it to a certain value  $\Delta_{cm}$  (Fig. 3.1), which is determined by the formula

$$\Delta_{cm} = \frac{\delta}{2} - \frac{\Delta_{\sigma}}{2}.$$

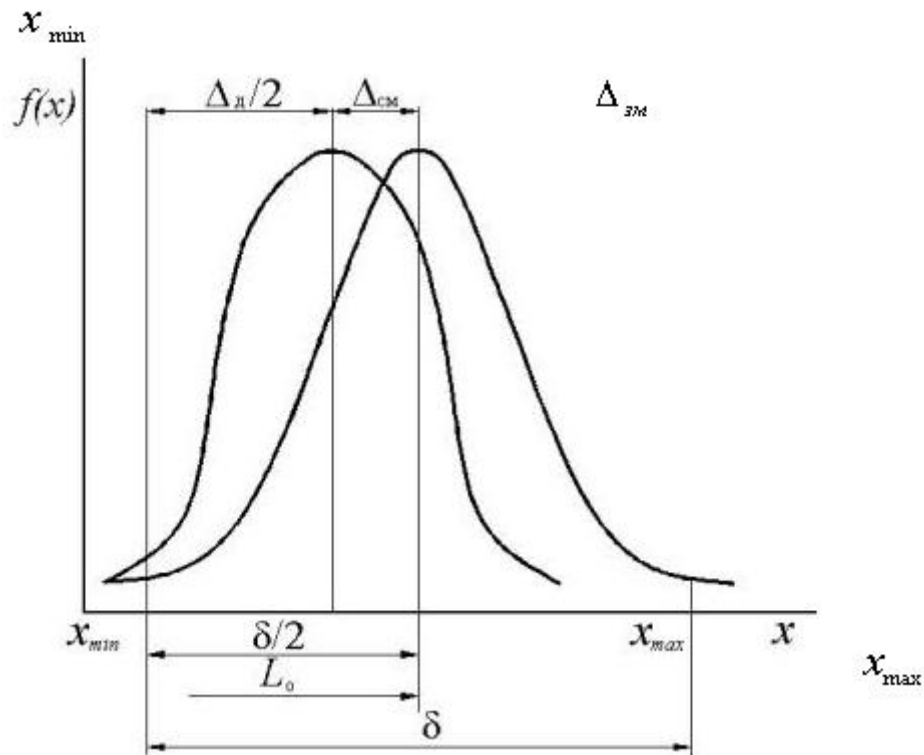


Figure 3.1 - Scheme for grouping the tolerance field and the size of the parts

Thus, the second criterion for the stability of the technological process is the condition for the permissible shift of the pre-set level of appearance

$$0 < \Delta_{\text{зм}} < \frac{\delta}{2} - \frac{\Delta_{\delta}}{2}.$$

In studying the stability of the machine on a sample of parts, made at one setting, measure the control size and determine its average arithmetic value  $\bar{X}$  and mean square deviation  $\sigma$ .

The arithmetic mean is determined by the formula

$$\bar{X} = \frac{\sum X_i}{m},$$

where  $X_i$  - size  $i$ -th details,

$m$  - number of parts in the sample.

Average square deviation

$$\sigma = \sqrt{\frac{\sum \Delta x_i^2 \cdot m_i}{m}},$$

where  $\Delta x_i$  - size  $i$ -th details,

$m$  - number of parts with this size.

The field of scattering of detail errors

$$\Delta_\delta = 6\sigma.$$

Offsets the level of tuning are determined by the formula

$$\Delta_{\text{зм}} = |\bar{X} - X_\varphi|,$$

where  $X_\varphi$  - the average size of the parts according to the drawing.

Resource accuracy at that

$$K_\Delta = \frac{\delta}{\Delta_\delta}.$$

And the relative bias ratio

$$K_{\text{зм}} = \frac{\Delta_{\text{зм}}}{\Delta_\delta}.$$

The obtained values are compared with the criteria of the stability of the technological process.

Less time consuming is the method of approximate definition of the mentioned criteria for small samples  $m = 5..10$  pcs due to the difference in the largest and smallest sizes.

$$\omega = X_{\text{max}} - X_{\text{min}}.$$

The arithmetic mean is determined by the formula

$$\bar{X} = \frac{\sum X_i}{m},$$

but the mean square deviation

$$\sigma = \frac{\omega}{d_m},$$

where  $d_m$  - coefficient, which depends on the number of parts in the sample.

Table 3.1 - The value of the coefficient  $d_m$

Number of parts in the sample, pcs ( $m$ )	5	6	7	8	9	10
$d_m$	2,326	2,543	2,704	2,284	2,970	3,077

More accurate results can be obtained if you take  $n$  samples. Then the parameters are determined by the following formulas.

$$\bar{X}_\phi = \frac{\bar{X}_1 + \bar{X}_2 + \dots + \bar{X}_n}{n} = \frac{\sum_{i=1}^n \bar{X}_i}{n}$$

$$\sigma_\sigma = \frac{\omega_1 + \omega_2 + \dots + \omega_m}{nd_m} = \frac{\sum_{i=1}^m \omega_i}{nd_m}$$

Progress

1. From a machine that works at the same setting, select 20 parts and measure their dimensions. Data of measurements are included in the table (appendix D).
2. Determine - the arithmetic mean and  $s$  is the mean square deviation of the size.
3. Determine the error of the D processing of the part, the resource accuracy of the KD, the relative bias Kfm.
4. Based on the data obtained, construct a block diagram of the tolerance field and dimension of the parts, compare the results obtained with the stability criteria, and conclude that the machine is to be configured.
5. To determine in an approximate way the criteria of the stability of the technological process in 5 parts and 4 samples in five parts. Find the results compared with the previous ones and determine the error.

Contents of the report

1. Number of defective parts in the sample.
2. The value of the mean arithmetic and mean square deviation of the size.

3. The value of detail processing error, resource accuracy and relative bias ratio.
4. Scheme of grouping the tolerance field and the size of the parts.
5. The significance of the criteria for the stability of the technological process is determined by an approximate method.

## Appendix D

Variant	Results of measurements					Size according to the drawing
1	10,25	10,39	10,35	10,11	10,34	
	10,08	10,50	10,05	10,17	10,20	
	10,15	10,34	10,17	10,22	10,28	
	10,30	10,25	10,28	10,37	10,21	
2	10,17	10,08	10,44	10,58	10,64	
	10,25	10,43	10,50	10,67	10,30	
	10,21	10,30	10,56	10,75	10,47	
	10,25	10,36	10,54	10,69	10,80	
3	20,13	20,05	20,26	20,26	20,32	
	20,17	20,24	20,30	20,32	20,27	
	20,11	20,21	20,25	20,37	20,41	
	20,23	20,26	20,27	20,35	20,39	
4	20,22	20,27	20,45	20,64	20,67	
	20,39	20,45	20,44	20,55	20,60	
	20,41	20,43	20,57	20,67	20,67	
	20,15	20,54	20,48	20,65	20,84	
5	30,14	30,17	30,20	30,05	30,23	
	30,05	30,10	30,21	30,27	30,34	
	30,47	30,15	30,33	30,34	30,25	
	30,25	30,27	30,27	30,36	30,38	
6	30,18	30,45	30,65	30,37	30,60	
	30,24	30,58	30,75	30,41	30,62	
	30,39	30,60	30,10	30,46	30,65	
	30,15	30,62	30,24	30,58	30,75	
7	40,12	40,29	40,15	40,40	40,34	
	40,20	40,35	40,23	40,12	40,37	
	40,25	40,45	40,28	40,23	40,05	
	40,48	40,07	40,35	40,27	40,47	
8	40,01	40,28	40,54	40,70	40,85	
	40,23	40,42	40,59	40,78	40,63	
	40,18	40,40	40,58	40,90	41,00	
	40,30	40,48	40,54	40,63	40,80	
	50,67	50,28	50,54	50,50	50,25	
	50,64	50,83	50,78	50,60	50,45	

	50,25	50,78	50,43	50,60	50,15	
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## **DETERMINATION OF FORCES ON THE HANDLES OF MOVEMENT AND CLAMPING OF ORGANS, BACKLASHES, ACCURACY OF MOVEMENTS ALONG THE LIMBS, THEIR CALCULATION**

**The purpose of the work:** gain experience in checking machines, mechanisms in terms of maximum effort on handles and levers used by working personnel, in compliance with safety regulations, as well as the ability to determine backlashes in reversible control bodies and bring them to the requirements of technical documentation. As an application, learn how to calculate limbo with the necessary discreteness and ease of use.

### **Equipment and measuring instrument**

1. The machines 1K62, 1341 or ЖА-280;
2. Dynamometer 0 ÷ 100H;
3. Indicator ICH-1 with a price of 0.01mm division;
4. Indicator rack;
5. A metal ruler L = 500mm or a caliper: Caliper – 3 (0 – 250mm);
6. Dynamometer ДОСМ 3 – 01 0 ÷ 1000H.

### **The order of work**

- 1) Checking the efforts of management bodies



All manually operated bodies on the machine (rudders, flywheels, etc.), as well as levers, are subject to inspection..

The tension dynamometer is installed on the line of action of the operator's hand, as shown in Fig. 1.

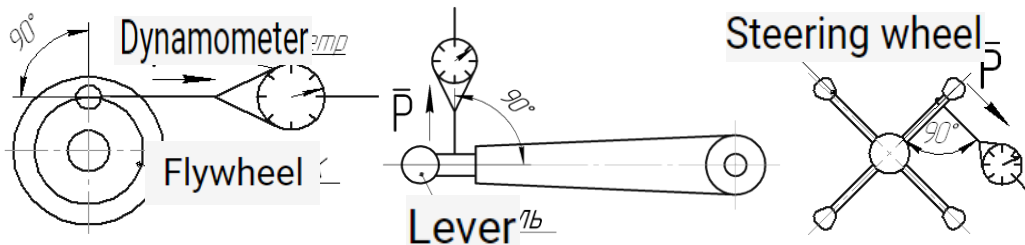


Figure.4.1-.Effort check schemes

According to the requirements ГOCT 12.2.009-80 „Metalworking machines. General safety requirements” the effort on the handles and levers (flywheels) of the bodies controlling the movement of the assembly units in case of their constant use should not exceed 40N. The effort on the same organs in case of their use no more than 5 times per shift should not exceed 150N, those used no more than 25 times per shift – 80H.

The required jerk force on different purpose levers and handles at the moment of the end of clamping or the beginning of unclamping should not exceed 500N.

The effort to move the rear headstock should not exceed 320N at the moment of contact. Fill in the table.

Table 1

№	Name and appointment of the body	The number of switches per shift	Efforts according to ГOCT 12.2.009-80,H		Actual effort, H		Meets or not the requirements of the standards
			contact	movement	contact	movement	
1	2	3	4	5	6	7	8



### 3) Calculation of limbs

3.1 The starting condition is the requirements of the item 1.3.2 ГОСТ 12.2.009-80, which concerns, first of all, the readability of limb indicators from a distance of at least 500 mm. This condition is fulfilled if the distance between the lines of the limb is at least 1.5...2 mm.

3.2 In order to ensure convenience, the limb must have a whole number of equal divisions, and in one revolution the movable body must move a whole number of millimeters (as an exception, the number 5 after the comma can be used, i.e. 0.5 mm).

3.3 For better observation of the numbers and divisions of the limbs, the total number of divisions should be a multiple of 5 or 10, and after every 5-10 divisions, a number from 0 to the amount of movement per revolution of the flywheel with the limb should be applied.

3.4 When developing the design of the device, the designer uses various schemes for manual movement of the organ:

- rack - rack gear;
  - gear - screw;
  - screw;
- } Conversion of circular motion  
in a straight line

In the case of using the "rail - rack gear" scheme, the displacement for one revolution of the rack gear is equal to:

$$S_{O\bar{O}} = \pi \cdot m \cdot z ,$$

where  $m$  is the module, mm;  $z$  is the number of teeth of the rack gear.

In the case of using the "gear - screw" scheme, the displacement per revolution is equal to:

$$S_{O\bar{O}} = i \cdot t ,$$

where  $i$  – is the gear ratio;

$t$  – screw pitch.

In the case of using a screw:

$$S_{o\delta} = t.$$

That is, everything depends on the kinematics and location of the limb (Fig. 3).

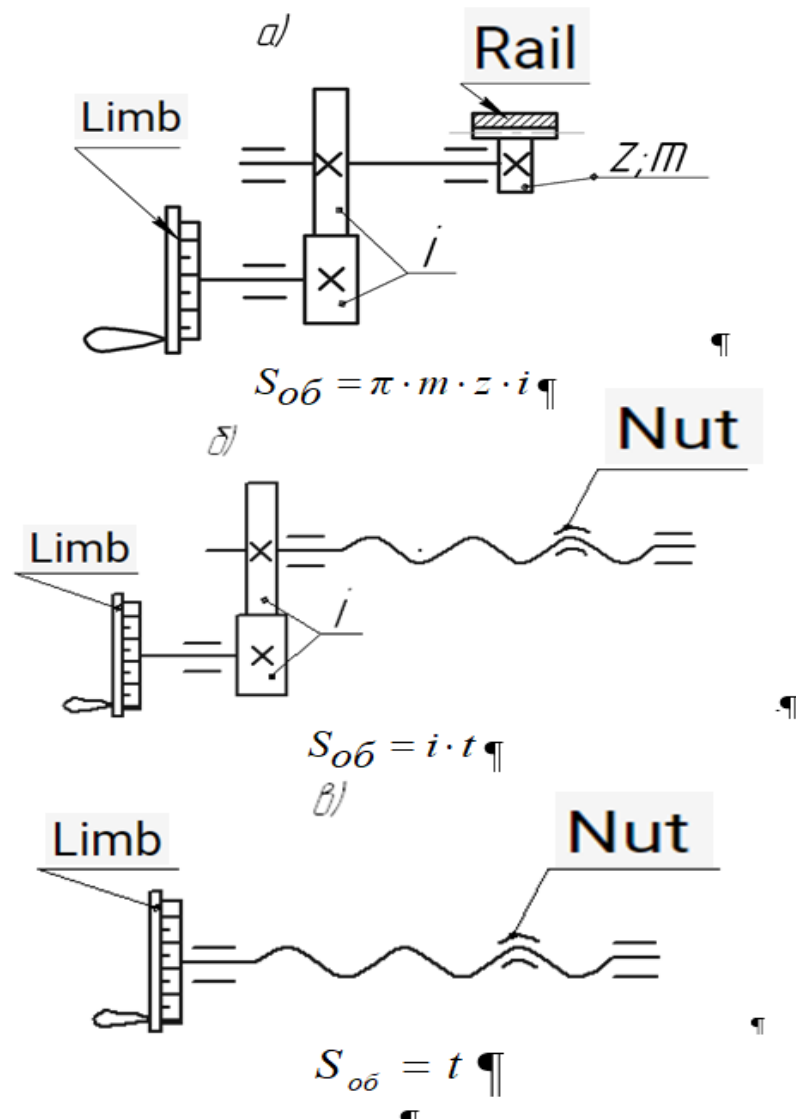


Figure 4.3 - Kinematic diagrams of limb installation

In the case of circular movement of the working body (turret head with a horizontal axis of rotation), the scheme has the following form (Fig. 4.4).

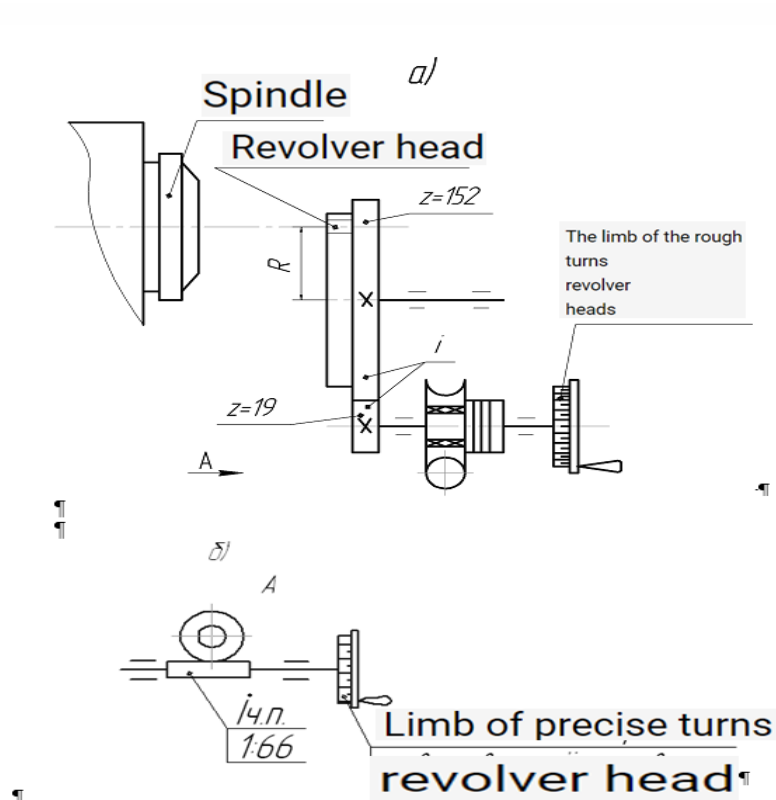


Figure 4.5 - Kinematics of the circular movement of the turret head with a horizontal axis of rotation

$$S_{об.зр.} = i \cdot 2\pi R \cdot q, ,$$

$$S_{об.точн.} = i_{ч.п.} \cdot i \cdot 2\pi R \cdot q, ,$$

where  $R$  – the radius of the location of the tool holes,  $R = 100$  mm;

$q$  – an error that takes into account the transformation of circular motion into rectilinear motion.

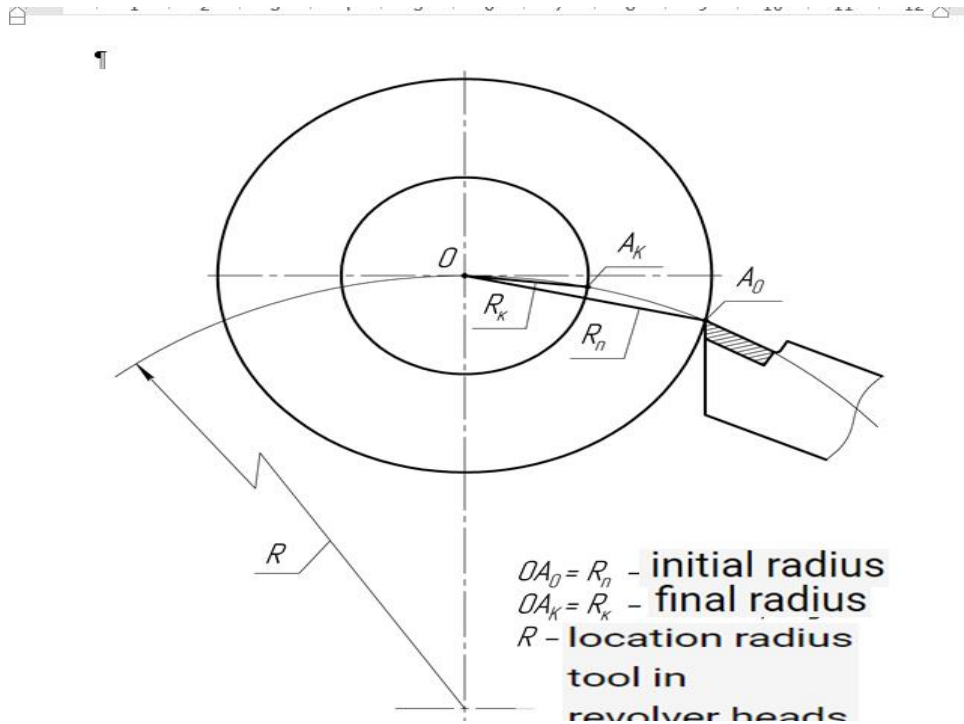


Figure 4.6 - Scheme of error generation when converting the circular trajectory of the tool into a change in the processing diameter

Perform limb calculations according to the initial data given in the table 3.

3.5. Determine the path of movement of the organ in one revolution of the flywheel with the limb and knowing the price of the division, we will calculate the number of divisions on the limb:

$$n = \frac{S_{o\bar{o}}}{\Delta S},$$

where  $\Delta S$  – the price of division.

The number of divisions must be a whole number and a multiple of 5 or 10. If necessary, the calculated amount is rounded and the error is determined:

$$\delta S = \frac{S_{o\bar{o}} - n \cdot \Delta S}{S_{o\bar{o}}} \cdot 100\%$$

3.6. The next step is determining the length of the limb scan:

$$L = n \cdot 1,5 \dots 2,$$

where 1,5... 2 mm - the distance between divisions.

3.7. We calculate the diameter of the limbus:

$$D = \frac{L}{\pi}$$

In case of obtaining unacceptable dimensions of the limb diameter, perform the following actions:

- with a small diameter, the distance between the pods is increased;
- if the diameter is large (exceeds the limits given in Table 3), proposals should be made to change the kinematics or increase the price of the division.

Table 3

№	Options	Drawing	Output data					Limiting parameter (limb diameter)*	The price of division, mm
			I	z	m	t	i <sub>ч.п</sub>		
1	3-01	3a	1/4	17	3	-	-	≤140	0,05
2	3-02	3б	1/2	-	-	10	-	≤120	0,02
3	3-03	3B	-	-	-	5	-	≤100	0,02
4	3-04	3a	1/3,5	19	2,5	-	-	≤140	0,05
5	3-05	4a	1/8	-	-	-	-	≤150	0,5
6	3-06	4б	1/8	-	-	-	1/6 6	≤120	0,05
7	3-07	3б	1/4	-	-	5	-	≤120	0,02
8	3-08	4a	1/5	-	-	-	-	≤150	0,5
9	3-09	4б	1/10	-	-	-	1/6 6	≤120	0,01
10	3-10	3B	-	-	-	5	-	≤140	0,01
11	3-11	3a	1/5	19	3	-	-	≤100	0,05
12	3-12	4a	1/10	-	-	-	-	≤120	0,5
13	3-13	3б	1/3	-	-	5	-	≤100	0,01
14	3-14	4б	1/8	-	-	-	1/8 0	≤120	0,02
15	3-15	3б	1/4	-	-	10	-	≤150	0,01
16	3-16	4б	1/10	-	-	-	1/6 6	≤120	0,01

17	3-17	3B	-	-	-	2, 5	-	≤110	0,05
18	3-18	4a	1/6	-	-	-	-	≤150	0,5
19	3-19	3a	½	17	2, 5	-	-	≤140	0,05
20	3-20	4b	1/6	-	-	-	1/10	≤120	0,01
21	3-21	3b	1/5	-	3	4	-	≤120	0,02
22	3-22	4a	1/7	-	-	-	-	≤100	0,5
23	3-23	3b	1/3	-	-	10	-	≤120	0,02
24	3-24	4b	1/7	-	2, 5	-	1/8 5	≤150	0,01
25	3-25	3B	-	-	-	8	-	≤120	0,02
26	3-26	4a	1/8	-	-	-	-	≤80	0,5
27	3-27	4b	1/5	-	-	0	1/5 0	≤100	0,01

\* Can be smaller by no more than 10 mm.

Provide a sketch of the calculated limb with the main parameters: diameter, number of strokes, size between strokes, division price.

**Note** When determining the error  $q_y$  the version shown in Fig. 4, use the following output data (Fig. 6).

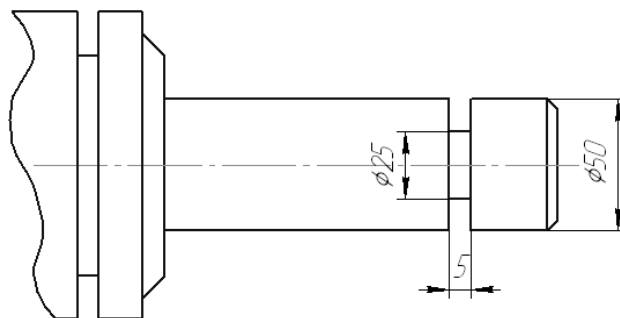


Figure 4.7 - Grooving of the groove due to circular movement  
revolver head



*Addition 1*Dynamometer calibration ДОСМ 3-01  
(factory № 500)

№	Nominal values of compression force, H	Indication of the indicator in divisions
1	0	1,000
2	100	1,730
3	200	2,453
4	300	3,176
5	400	3,895
6	500	4,622
7	600	5,344
8	700	6,063
9	800	6,786
10	900	7,505
11	1000	8,220

## EFFECT OF CLAMPING FORCE ON PROCESSING ACCURACY

**The purpose of the work:** one of the influencing factors on processing accuracy is the clamping force of the workpiece, as well as its rigidity. This influence is especially important when processing hollow workpieces (boring, turning, external and internal grinding, etc.), with their clamping in a self-centering chuck.

The case of boring a ring workpiece (Fig. 1), which is fixed in a 3-jaw self-centering chuck, is considered.

Using this example, students should gain experience in the mandatory consideration of the basing scheme and fixation of the workpiece before processing for accuracy after its disassembly.

### **Measuring instrument**

1. Micrometer MK 25-50;
2. Micrometer MK 0-25;
3. Calipers 18-50;
4. Indicator with 0.01 mm division value.
5. A set of finite plane-parallel measures of length (large).
6. Cutting tool. Boring cutter with soldered plate T15K6. Geometry: front angle  $\gamma = +8^\circ$ , back angle  $\alpha = 6^\circ$ , the main angle in the plan  $\varphi = 45^\circ$ , angle of inclination of the main cutting edge  $\lambda = -5^\circ$ , auxiliary angle in the plan  $\varphi_1 = 30^\circ$ , radius of rounding at the top  $r = 0,1$  mm.
7. Dynamometric key.

The theoretical dependencies are given below.

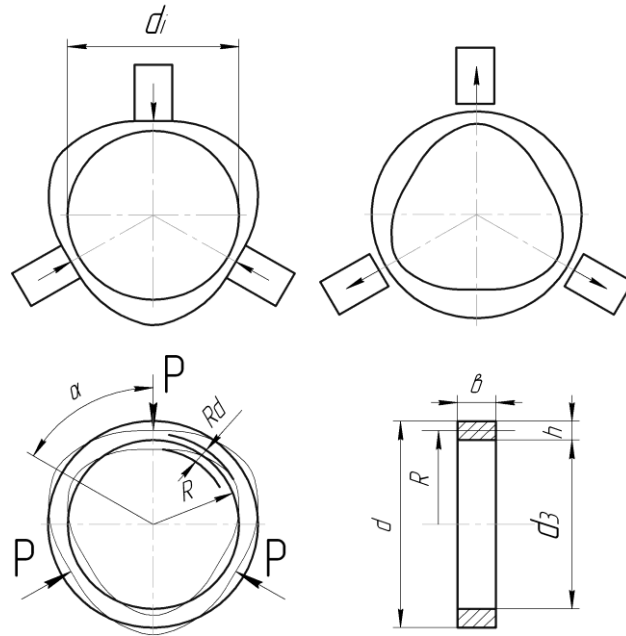


Figure 5.1 - Boring of the ring. Steel 45

$$R_d = K_n \times P_{sp} \times \frac{R^3}{I \times E}, \quad (1)$$

where  $P_{sp} = \sum P$ ;  $R$  – the radius of the neutral axis;

$I$  – the moment of inertia of the cross-sectional area of the workpiece,  $I = \frac{b \times h^3}{12}$ ;

$E$  – modulus of elasticity of the workpiece material;

$K_n$  – coefficient, which depends on the number  $n$  of clamping places of the workpiece (Fig. 5.2).

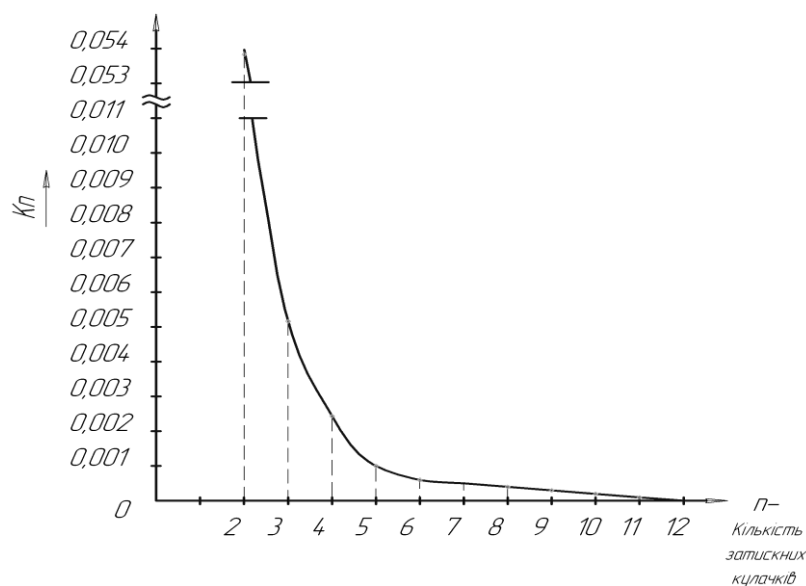


Figure 5.2 - Calculated coefficient values  $K_n$

$$K_n = \frac{1}{2n} \left( \frac{1}{\sin \frac{\pi}{n}} - \operatorname{ctg} \frac{\pi}{n} - \frac{\pi}{2n} \right) \quad (2)$$

$$M_{pi3} < M_{kp},$$

where  $M_{kp}$  – the countering moment from the side of the clamping mechanism;

$M_{pi3}$  – moment from the cutting force  $P_z$ .  $M_{pi3} = P_z \frac{d_i}{2}$  ( $d_i$  – processed diameter).

In addition, there are forces  $P_x$  and  $P_z$ .

$$\text{Clamping force per cam: } P = k \left[ \frac{P_x}{3} + \frac{P_y}{2} + \frac{P_z \times d_i}{3d_3} \right] f_{TP},$$

where

$f_{TP}$  – coefficient of friction;

$k$  – clamping force reserve factor.

The total clamping force of the workpiece:

$$P_{sp} = nP,$$

where  $n$  – the number of clamping positions.

From every force  $P$  power  $Q_1$  arises.

There will be a clamping force:

$$n \times Q_1 = \frac{2M_{kp}}{fd_i}, \text{ H,} \quad (3)$$

where  $f$  – coefficient of friction;

$$M_{kp} = \frac{n \times Q_1 \times f \times d_i}{2}, \text{ H} \cdot \text{mm.} \quad (4)$$

On the other hand

$$P_{sp} = \frac{P_z \times d_i}{f \times d}, \text{ H;} \quad (5)$$

$$P_z = P_{\text{пит}} \times t \times S, \quad (6)$$

where  $t$  – cutting depth, mm;

$S$  – feed, mm/rev;

$P_{num}$  – specific cutting force, which depends on the workpiece of material, N/mm<sup>2</sup>.

$$P_{sp} = \frac{P_{\text{пит}} \times t \times S \times d_i}{f \times d}, \text{ H.} \quad (7)$$

As the cutting edge dulls  $P_{num}$  increases to 30%. Therefore, it is necessary to enter the reserve factor of the clamping force  $k = 2 \dots 2,5$ .

Dynamic cutting force

$$P_{z, \text{дин}} = K \times P_z = K \times P_{num} \times t \times S, \quad (8)$$

where

$$P_{sp} = \frac{K \times P_{\text{пит}} \times t \times S \times d_i}{f \times d}, \text{ H,} \quad (9)$$

$K$  – for smooth cams = 0,1...0,15.

Centrifugal force acting on the clamping jaws:

$$F_0 = M \times R \times \omega^2 = \frac{G \times R \times \omega^2}{g} = 0,102G \times R \left( \frac{\pi \times n}{30} \right)^2, \quad (10)$$

where  $M$  – cam weight, kg;

$R$  – radius from the axis of the spindle, s<sup>-1</sup>;

$\omega$  – angular velocity, s<sup>-1</sup>;

$G$  – cam weight, H;

$g$  – acceleration of free fall, m/s<sup>2</sup>;

$n$  – spindle rotation frequency, min.<sup>-1</sup>.

$$Q_{ст} = Q_{\text{дин}} \pm F_c, \text{ H,} \quad (11)$$

where „+” refers to the external clamp;

„-” – to the clamp on the inner diameter.

$$n_{\text{доп}} = \frac{30}{\pi} \sqrt{(Q_{ст} - Q_{\text{дин}}) \frac{1}{M \times R}}, \text{ s}^{-1}, \quad (12)$$

$Q_{ст}$  and  $Q_{\text{дин}}$  у даН (da – deka = 10<sup>1</sup>).

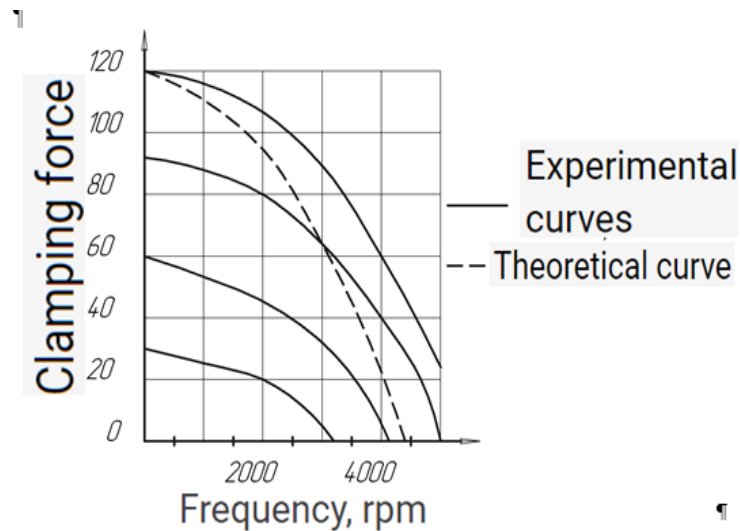


Figure 5.3 - Dependence of the clamping force of the wedge chuck on the spindle rotation frequency

### **Procedure for conducting the experiment**

1. Measure the outer diameter of the workpiece  $d$ , inner diameter  $d_3$ , width  $b$ . Enter the data in the table. Accuracy of measurements  $\pm 0,05$  mm.
2. Calculate the required clamping force of the workpiece according to formula 9, setting the cutting depth  $t = 0,5$  mm;  $S = 0,05$  mm/rev;  $n = 500$  mm/rev..
3. Fasten the workpiece in the 3-jaw chuck, withstanding the moment on the key, determined by dependence  $M_{kp} = 1Hm \rightarrow 250H = \sum P = P_{sp}$  (Addition ). Draw three lines on the end of the workpiece opposite the cams (cartridge  $\text{Ø}250\text{mm}$ ).
4. Drill a hole.
5. Measure the diameter of the hole with a feeler gauge, determine its ovality.
6. Incompletely squeeze the ring and check the hole, determine the deviation from roundness  $R_d$ .
7. Conduct a theoretical definition  $R_d$  and compare with experimentally obtained.
8. Conduct the experiment twice.

№	Preparation				boring	Cutting the hole after removing the clamping forces (without removing from the machine)						R <sub>d, теор</sub>	theoretical calculations	theoretical calculations			
	d, mm		d <sub>3</sub> , mm			d <sub>i</sub>	R <sub>декп</sub> ,								%		
	0°	90°	0°	90°			ε, mm	0°	90°	0°	60°					120°	180°
I																	
II																	

Torque on the key of the 3-jaw self-centering chuck  
depending on the total clamping force of the workpiece

№	The diameter of the cam cartridge is 3 ГОСТ 2675-80	The maximum total clamping force of a 3-jaw chuck, H	Maximum torque on the key, H·m	The total clamping force at the torque on the key 1H·m
1	80	7840	34,3	228,6
2	100	8820	49,0	180
3	125	16660	73,5	226,7

4	160	24500	122,5	200
5	200	29400	156,8	187,5
6	250	44100	176,4	250
7	315	53900	196	275
8	400	63700	274,4	232
9	500	83300	352,8	236
10	630	102900	450,8	228



## THE INFLUENCE OF TEMPERATURE DEFORMATIONS ON THE ACCURACY OF PROCESSING PARTS

**The purpose of the work:** acquiring skills in checking the temperature deformations of a lathe-screw-cutting (lathe-turret) machine and determining their influence on the accuracy of processing.

### Modes of conducting experiments

1. Spindle revolutions per minute – 1400...2000.
2. Total test time – 120 min.
3. Control intervals – 20 min.

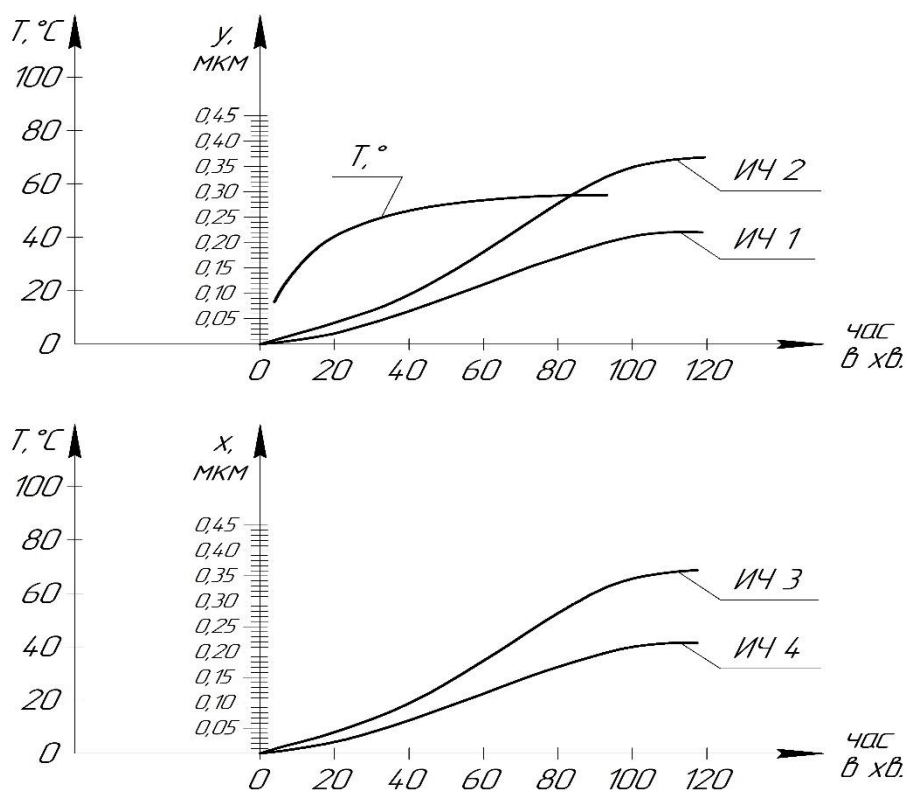


Figure 5.2 - Graphs

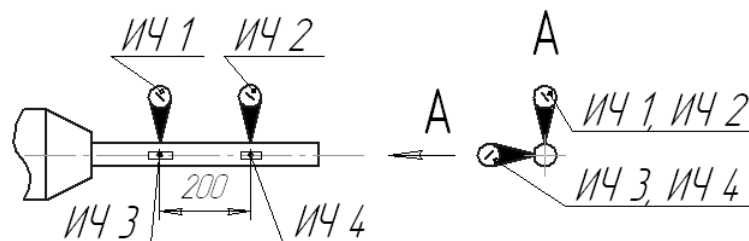
### Means of testing

1. Time-type indicator with a price of 0.01 mm division - 4 pcs.

2. Time-type indicator with a division price of 0.001 mm - 1 pc.
3. Stopwatch (clock).
4. Thermometer - 2 pcs.
5. Control mandrel based on the external cone and the end of the spindle flange or in the spindle hole.
6. A special device for installing 4 indicators.

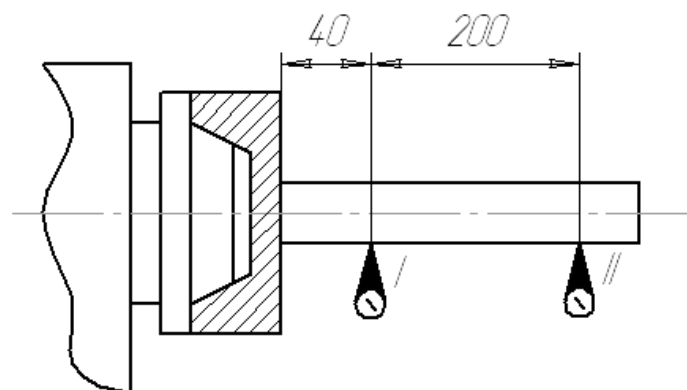
Calculate the theoretical errors caused by temperature deformations when processing a diameter of 30 mm on a length of 100 mm and the location of the cutter in the horizontal plane at a fixed time (60 min. and 120 min. of machine operation).

### Schemes of installation of indicators



### The order of work

1. The mandrel is fixed on the spindle in such a way that its radial runout is minimal (check in two places: near the end of the spindle and at a distance of 200 mm)



Note. The mandrel can be inserted into the tapered bore of the spindle.

2. Use chalk to make marks on the spindle and spindle headstock for the possibility of stopping the rotation of the spindle in the same position.

3. Install a device with four indicators in the turret (or cutter holder), bring it to the control point, set the indicators to the zero position and fix the position of the caliper in the longitudinal direction.

4. Return the caliper to the original position.

5. Record the temperature of the front and rear supports of the spindle.

6. Include spindle revolutions.

7. Every 20 min. bring the caliper to the front fixed position, control the displacement of the spindle mandrel horizontally and vertically when aligning the marks of the spindle and the spindle headstock body.

8. Build graphs:

- change in the temperature of the supports;
- displacement of the mandrel along the X axis (two positions);
- displacement of the mandrel along the Y axis (two positions);
- spatial displacement of the mandrel.

9. Perform appropriate calculations of temperature shifts - accuracy for the length of the treated surface  $L=100$  mm, with a diameter of 30 mm.

9.1. Average diameter errors.

9.2. Conicity.

9.3. Saddle-, barrel-shaped.

10. Provide specific proposals for reducing the influence of temperature deformations on the accuracy of processing.

## **DETERMINATION OF THE DEVIATION FROM THE STRAIGHTNESS OF THE MOVEMENT OF THE WORKING BODY IN A GIVEN PLANE**

**The purpose of the work:** Acquisition of skills in checking machines during their installation for straightness and flatness of movement of working bodies using bubble levels.

**Terms and explanations.** Deviation from the straightness of the movement of the working body in a given plane – the largest algebraic difference of the ordinate of the trajectory of the functional point of the tested working body or the ordinate of the trajectory of the relative movement of the functional point of the stationary part of the machine in relation to the tested working body, in a rectangular coordinate system, the abscissa axis of which passes through the beginning and end of the trajectory.

Functional point – the point that determines the shaping of the processed product.

The total deviation from the straightness and parallelism of the trajectory of the movement of the working body relative to the planes or axis – the largest distance difference at a given length of movement between the trajectory of the functional point of the movable working body of the machine tool (or the trajectory relative to the movement of the functional point of the stationary part of the machine tool in relation to the movable working body of the machine tool) and the plane or axis relative to which the measurements are carried out.

### **Equipment and measuring instrument**

1. Machine tools: 1K62, 1341, 1B340Φ30, ЖА-280.
2. Bubble level with a division price of 0.02 mm on a length of 1 m.
3. Metal ruler  $L = 500$  mm.

Note. When using a bubble level, the reading must be carried out at the two ends of the bubble and the result of the measurements taken as the average of the two readings (readings).

Straightness measurement method using a level.

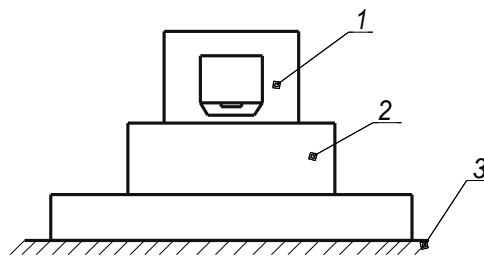


Figure 7.1 - The scheme of measurements is shown

1 – Level, 2 – working body (caliper), 3 – longitudinal or transverse guides.

Level 1 is set on the tested working body 2 in such a way that the bubble is in the center of the scale (this is achieved by placing the probes of the required total thickness under one of the corners of the level).

The working body being checked is moved to a given length in steps, the size of which is determined by standards for the accuracy norms of specific types of machines, depending on the length and accuracy of the surface being checked. If there are no such instructions, then the measurement interval (step) is taken to be equal to 0.05-0.3 of the length of the surface being tested (movement lengths), but not more than 1000 mm.

Deviations from the straightness of the movement trajectory in units of angle are determined by the largest algebraic difference in the level indicators at a given length of movement.

Constancy of the angular position of the moving working body

Verification method: using one level.

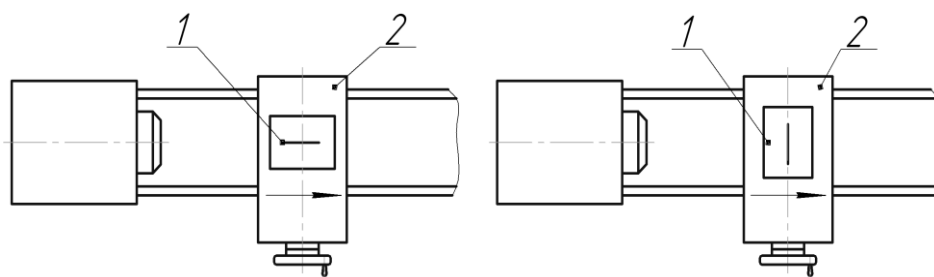


Figure 7.2 - The scheme of measurements is shown

1 – level, 2 - working body.

Conducting measurements: Level 1 is set on the working body being tested, in the direction of its movement or perpendicular to it. The working body 2 is moved in steps as described above. Level readings are read in all positions of the working body. The deviation from the constancy of the angular position is equal to the larger algebraic difference of the level readings. It is allowed to carry out measurements in two directions at the same time.

Limit values of the steps are measured when determining deviations from the straightness of the surface can be accepted according to the data in the table 1

Table 1

The length of the working movement L, mm	The largest step length of measuring points $t_{\max}$ , mm for flatness tolerance, $\mu\text{m}$		
	to 20	more 20 to 50	more 50 to 100
To 100	L/4	L/2	L/2
More 100 to 250	L/6	L/4	L/2
More 250 to 630	L/8	L/6	L/4
More 630 to 1000	L/10	L/8	L/6
More 1000 to 2500	L/12	L/10	L/8
More 2500 to 4000	L/14	L/12	L/10
More 4000 to 10000	L/16	L/14	L/12

Determination of the deviation from the straightness of the surface – carried out according to a graphic image of the profile of the surface being checked, in a given cross-section relative to the adjacent straight line.

According to the definition of the adjacent straight line according to ГОСТ 24642-81 two cases of tangent of an adjacent straight line to the profile of the surface being checked in the given section are possible:

– an adjacent line tangent to the profile of the tested surface in the given section at the two highest points (Fig. 3); in this case, the highest points can be the end points

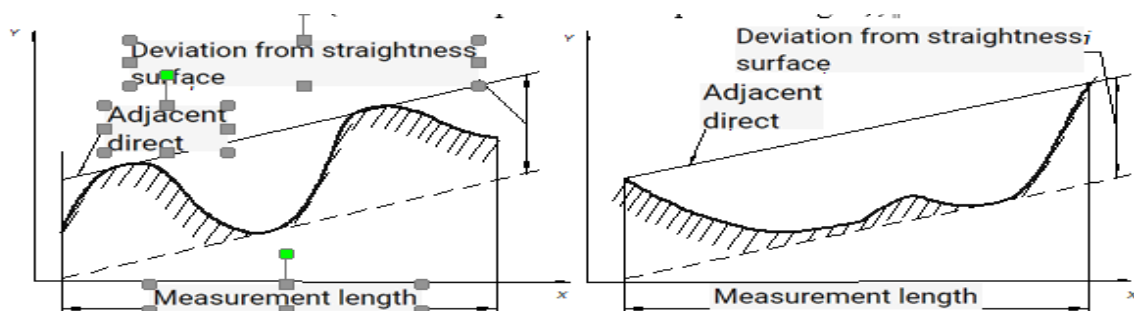


Fig. 3. Fig. 4.

– an adjacent straight line tangent to the profile of the tested surface in a given section at one highest point and parallel to the straight line connecting two low points (the output form of the real profile - Fig. 5); in this case, the highest points can be the endpoints of the measured section (Fig. 6)

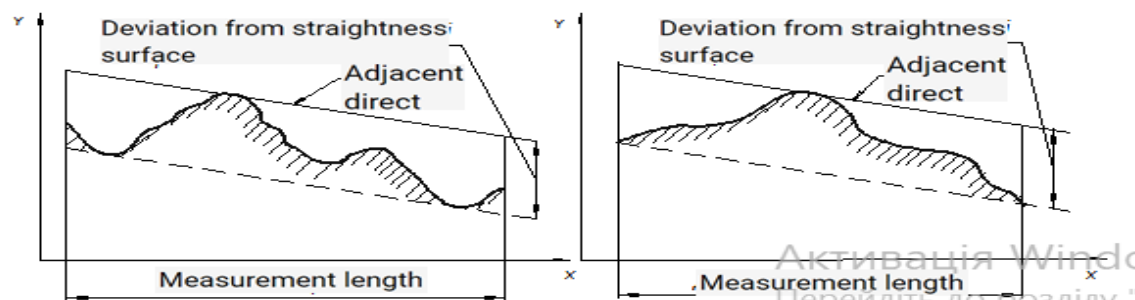


Рис. 5. Рис. 6.

of the measured section (concave shape of the real profile - Fig. 4);

If it is possible to determine which case corresponds to the position of the adjacent straight line based on the nature of the profile of the inspected surface in a given section, then the deviation from straightness in the plane is determined for each case. The definition of an adjacent straight line will correspond to its position at which the deviation from the straightness of the surface is smaller.

It is allowed to determine the deviation from the straightness of the surface in relation to the straight line that passes through the extreme points of the profile of the

tested surface in the given section. At the same time, the extreme points of the profile should be located at the same distance from the measure of straightness (verifier ruler, optical ruler and the like).

Deviation from straightness in a given cross-section of the tested surface in this case is determined without drawing a graph as the largest algebraic difference in the readings of the measuring device along the length of the measurement.

### Determination of the deviation from the straightness of the surface by calculation.

When measuring deviations from the straightness of surfaces at individual points of the profile of the tested surface in a given section with the same step from the relative base created by mechanical means or a light beam, the "absolute" differences in the heights of the positions of individual points relative to the base for measurement are obtained.

The shape of the measured profile of the tested surface in the given cross-section, obtained by plotting the graph according to the measured value in the corresponding longitudinal and vertical scale, is presented in fig.7.3.

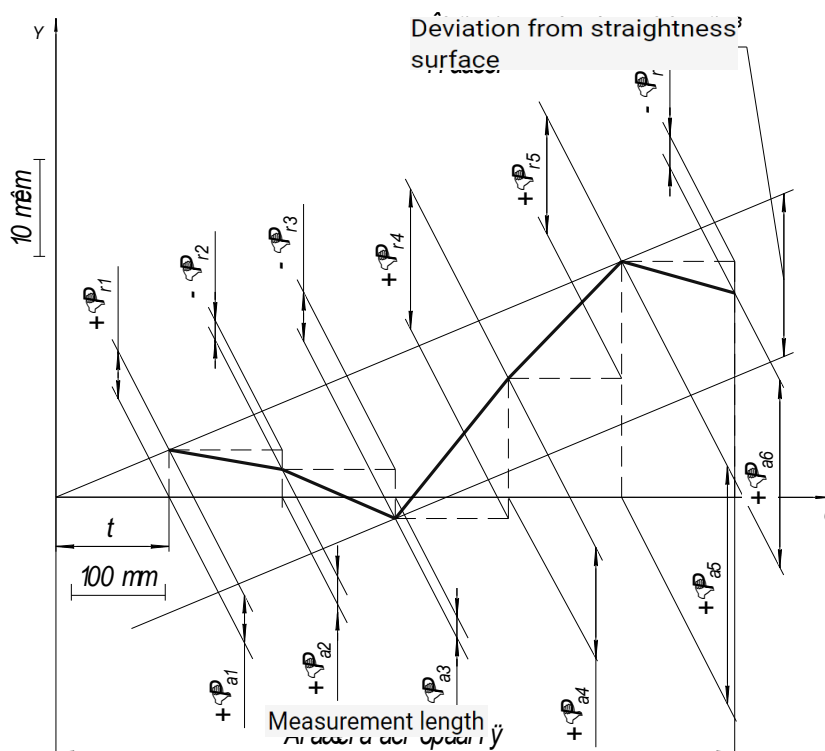




Figure 7.3 - Corresponding longitudinal and vertical scale

When measuring relative changes in the angular position of the line connecting two adjacent points of the profile of the cross-section being tested, it is determined in micrometers the relative height difference of these points  $\Delta P_{ri}$  and (or) average arithmetic values  $\Delta \bar{P}_{ri}$  by formulas:  $\Delta P_{ri} = U_i C t = U_i K_i$ ;

$$\Delta \bar{P}_{ri} = \bar{U}_i C t = \bar{U}_i K_i,$$

where  $U_i$  – angular position of the line that connects two adjacent points of the profile of the cross-section to be checked (in divisions of the level);

$\bar{U}_i$  – arithmetic mean of measurements (in level divisions);

$C$  – the nominal value of one scale division (division price) of the level, for example 0.01 mm/1000 mm;

$t$  – step of measuring points, mm;

$K_i = C_i$  – constant.

Absolute dispersion of the measurement points of the profile of the cross-section being tested  $\Delta P_{ai}$  and (or) their average arithmetic value  $\Delta \bar{P}_{ai}$  relative to the measurement base (axis X - Fig. 7) is calculated using formulas:

$$\Delta P_{ai} = \sum_{i=1}^n \Delta P_{ri}; \quad \Delta \bar{P}_{ai} = \sum_{i=1}^n \Delta \bar{P}_{ri};$$

When measuring the angular position of the line connecting two adjacent points of the profile of the inspected section, the relative difference in the heights of the points of the profile and (or) their average arithmetic values in arc seconds are determined by the formulas:  $\Delta P_{ri} = t \cdot tg \Delta x_i$ ;  $\Delta \bar{P}_{ri} = t \cdot tg \Delta \bar{a}_i$ .

Example. The straightness of the longitudinal section of the surface was checked with a level with a division price of 0.01 mm/1000 mm and a measuring bridge with a distance between reference points of mm.

Measurements were performed 3 times.

The results of measuring the angular position of the line connecting two adjacent points of the profile of the cross-section of the surface being tested are given in table 2.

Table 2.

Measurement number	$U_i$ (in level divisions) on the plot				
	0-1	1-2	2-3	3-4	4-5
1	+3,0	-1,5	+1,5	-1,0	+2,5
2	+2,0	-2,0	+2,5	-1,0	+4,0
3	+2,5	-1,0	+2,0	-1,0	+2,5
$\bar{U}_i = \frac{\sum_{i=1}^n U_i}{3}$	+2,5	-1,5	+2,0	-1,0	+3,0

The value of the relative difference in the heights of neighboring points of the profile of the cross-section being tested  $\Delta P_{ai}$  and the absolute height difference  $\Delta P_{ai}$  given in the table 3 and 4.

Table 3.

Measuring point	$\Delta P_{ai}, \mu\text{m}$
0	0
1	5
2	2
3	6
4	4
5	10

Table 4.

Measuring area	$\Delta P_{ri}, \mu\text{m}$
0-1	+5
1-2	-3
2-3	+4
3-4	-2
4-5	+6

A graphic representation of the measured values at a horizontal magnification of 10:1 and a vertical magnification of 2000:1 (conditionally) is shown in Fig.7.4.

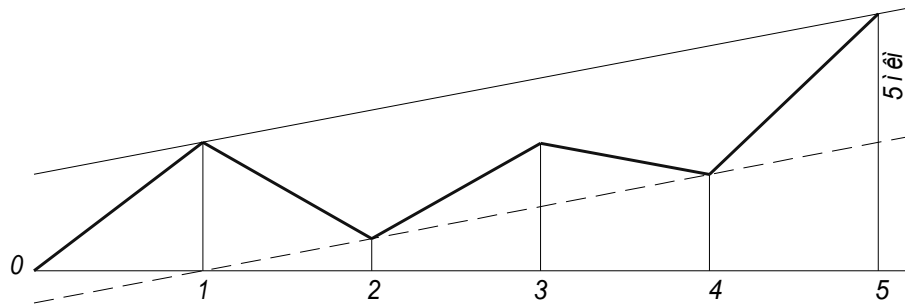


Fig 7.4 - A graphic representation of the measured values at a horizontal magnification

The deviation from straightness is 5 μm.

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