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Methodical instructions for performing Course Project «Technology of Mechanical Engineering» for foreign students

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1. Author:
   Associate professor of the TAMP department __________ Victor Kozlov

2. Reviewer:
   Professor of the TAMP department,
   Doctor of technical sciences ______________ Sergey Petrushin

The methodical instructions for performing **Course Project «Technology of Mechanical Engineering»** have been submitted to the approval of the Institute of Cybernetics and meets the curriculum requirements.

3. Head of Studies Providing Department TAMP ___________ Vladimir Skvortsov

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1. INTRODUCTION

Production efficiency, its technical progress, quality of let out production in many respects depend on outstripping development of manufacture of the new equipment, machines, machine tools and devices, from the introduction of methods of the technical and economic analysis ensuring the solution to technical questions and economic efficiency of technological and design development.

The purpose of this **Course Project** is to outline the development of technological process and designing of the attachment for milling key slot 8H9 (clamping on V-block with a pneumonic drive). It enables to receive the necessary skills for the development of part manufacturing technology and will improve the theoretical knowledge of the discipline "Mechanical Engineering".

Production process is a set of all actions of people and tools needed at the enterprise for manufacturing and repairing products. The process covers: preparation of means of production and organization of workplace maintenance; receipt and storage of materials and semi-finished products; all stages of manufacturing process, products assembly; transportation of materials, workpieces, components and finished products; technical inspection at all stages of production; packaging of finished products and other activities related to the production of products. The most important element of the production process is the process planning, which includes engineering design of the product and manufacturing process planning, and production scheduling as well.

Manufacturing process is a part of the production process, that incorporates actions aimed at changing and (or) defining the state of the subject of labour. Various kinds of products are referred to the subjects of labour.

Manufacturing processes are divided into the processes of machining, assembling, casting, heat treatment, coating, etc.

For implementation of any process a set of means of labour, called the ***means of manufacturing***, is required.

Means of manufacturing are divided into manufacturing equipment and manufacturing tooling. ***Manufacturing equipment*** is the means of manufacturing, in which materials and workpieces, as well as the tools, are placed to perform a certain part of the manufacturing process. Examples of manufacturing equipment are machine tools, presses, casting machines, furnaces, electroplating baths, etc.

Means of manufacturing, which are supplementary to the manufacturing equipment, are known as ***manufacturing tooling*** (cutting tools, dies, fixtures for mounting workpieces, measuring instruments, etc.).

Manufacturing processes are performed at the work places. A ***workspace*** is an elementary unit of the company structure that incorporates various workers, manufacturing equipment or part of a production line, as well as tooling and (for a limited period of time) articles of manufacture.

Manufacturing processes are divided into operations. ***Manufacturing operation*** is a finished part of the manufacturing process that **is accomplished** on a

single workplace. Operation involves all actions of equipment and worker (or workers) upon one or more simultaneously machined or assembled subjects of production. During machining on a machine tool, operation comprises all actions of a machine operator, as well as automatic motions of the machine carried out until workpiece is unloaded from the machine.

Operations are characterized by continuous action upon the subjects of production. Let us take, for example, turning of a batch of stepped shafts which are cut from a rolled bar into workpieces a little bit longer than the length of a finished shaft.

If each shaft is turned at one end first, then reclamped and turned at the other end, then the turning of the shafts is a **single operation**.

If all the shafts of a batch are turned at first end, take off from the machine tool, **place into container**, then **workpiece is taken from a container,** and then these shafts are turned at the other end, then the turning of the shafts constitutes **two operations**.

The content of operations may vary widely – from work performed on a single machine to the work performed on the production line.

Names for operations are given **according to the technological equipment** on which these operations are performed. The examples are: turning, milling, automatic, pressing, etc.

The operations are numbered in **arithmetic progression** (5, 10, 15,...). Zeros can be added to the left of the numbers.

Operation is an essential part of the manufacturing process in terms of organizational and economics. Operations are assigned by the **standards of time**, which determine work-intensiveness of the manufacturing process, required number of production workers and required means of production (equipment, fixtures, tools, etc.).

Operations are divided into **set-ups**, positions, **processing steps** and **cutting passes**.

Set-up is a part of a manufacturing operation performed with the machined workpiece or assembled unit being constantly clamped.

For example, if the stepped shaft during turning operation is clamped and turned at one end and then reclamped and turned at the other end, thus, the **operation consists of two set-ups**.

Set-ups are denoted by capital letters of the alphabet (A, B, C, ...).

Processing step is a finished part of the manufacturing operation performed by the same means of technological equipment with the technological parameters and clamping being unchanged.

Processing step is characterized by application of the same type of a tool, or machining/assembling the same surfaces of parts, as well as constant technological parameters.

When a single surface is cut by a single instrument, the processing step is called ***simple*** or ***elementary processing step***. Such processing step, when several tools are used simultaneously is called ***complex processing step***.

When the parts are machined on the **CNC machines**, a set of surfaces can be successively cut by a single cutting tool (by a cutter, for example) as it moves along a path defined by the program. In this case the **processing step** is called an ***instrumental step***.

The names of processing steps are given in the **imperative mood** (turn the surface ..., cut the thread ..., broach the slot ...). Processing steps are numbered by natural numbers (1, 2, 3 ...).

Along with the processing steps, auxiliary steps are implemented.

Auxiliary step is a finished part of the manufacturing operation that consists of actions of a worker and (or) equipment that are not accompanied with changing the properties of the subjects of labour, but are necessary for processing step execution.

Examples of auxiliary steps include setting up the workpiece, tool change, for example, by indexing the lathe tool post, etc.

Processing steps are divided into cutting passes.

Cutting pass is a finished part of the processing step and consists of a single movement of the cutting tool relative to the workpiece, accompanied by change in shape, size, surface quality and properties of the workpiece.

Action is a finished set of worker activities performed during the processing step or its part, united by one purpose. For example, to set the work-piece into the fixture it is necessary to perform the following actions: take the workpiece from the container, place it into the fixture and clamp the workpiece in the fixture.

2. DEFINITION of a MANUFACTURING TYPE

The annual program of products N = 10000 pieces.
The real annual fund of an operating time of the equipment is determined from the recommendations for the table 4 [4, page 23] for work in 2 shifts: F_r=4015 h.
We determine the time interval, during which products or workpieces of certain names are periodically issued, so called ***Takt time***:

$$t_d = \frac{F_r \cdot 60}{N} = \frac{4015 \cdot 60}{10000} = 24.9\left(\frac{\min}{piece}\right),$$

where F_r – is the real (actual) annual fund of an operating time of the equipment, hours; N – the volume of production for the same period, pieces.
The data on existing (similar) factory technological process or on integrated fixing of operations are given in tab. 1.

Table 1. Duration of operations of the existing factory technological process, (Operation Cycle Per Part (OCPP) for each operation)

№ of operation	The name of operation	t_{oc}, min.
1	Turret-lathe	1.96
2	Turret-lathe	0.45
3	Vertical - drilling	0.02
4	Round grinding	0.32
5	Flat grinding	0.15
6	Inner grinding	3.15
	Total floor-to-floor (OCCP) time $T_f = \sum t_{oci}$ = 5.93 min.	

Quantity of operations n=6.
Total floor-to-floor time (piece-time) (**Operation Cycle Per Part** (**OCPP**) T_{oc}) of all operations:

$$T_f = T_{oc} = \sum t_{oci} = 5.93 \text{ min.}$$

We shall define (determine) **average** floor-to-floor time (**Operation Cycle Per Part** (**OCPP**) $t_{oc\ av}$) according to the formula:

$$T_{f\ av} = T_f / n = 5.93/6 = 0.988 \text{ min.}$$

Method of production is defined according to ***production factor k_{pf}*** that is the ratio of **number of all different operations** done or to be done **during a month** to the **number of working places**. In other words, this factor shows the average amount of operations done or to be done for the one working place during a month. Production factor is: 1 for mass production; from 1 to 10 for large-batch production; from 10 to 20 for medium-batch production; from 20 to 40 for small-batch production; 40 and more for job production.

Method of production is **also** can be defined according to ***production factor*** $\boldsymbol{k}_{\mathbf{pf}}$ that is the ratio of ***Takt time*** t_d to **the average floor-to-floor time** $T_{f\ av}$.

We shall define ***production factor*** k_{pf} (factor of manufacturing type) according to the formula:

$$k_{pf} = t_d / T_{f\ av} = 24.9/ 0.988 = 25.2.$$

Since $20 \le k_{pf} \le 40$, the **type of manufacture** is a **small-batch production**.

2.1. Calculation of parts quantity in a set (batch size)

The annual program of release N = 10000 pieces; $T_{f\,av}$ =0.988 min.

Periodicity of start - release of products a = 5 days.

Number of working **shifts** in **one year** for **1 shift** F = 240 shifts.

We shall define settlement quantity of parts (details) in a **batch** according to the formula:

$$n = N \times a / F = 10000 \times 5/240 = 208 \text{ pieces},$$

where a – is the quantity of storage days. For small and inexpensive details it is 5…10 days. But more storage days means more unfinished manufacturing, which is why we accept 5 days.

The settlement number of shifts for processing of parts set in a site (shop) is defined according to the formula:

$$c = (T_{f\,av} \times n)/ (240 \times 0.8) = (0.988 \times 208)/ (240 \times 0.8) = 1.06.$$

The accepted number of shifts for machining of a batch in a site: c_{ac}=1 shift.

The accepted number of details in a batch is:

$n_{ac} = c_{ac} \times \boldsymbol{F} \times 0.8/ T_{f\,av} = 1 \times 240 \times 0.8/0.988 = 194$ pieces ≈ 200 pieces,
taking into account percentage of invalid parts (ordinary 3% , i.e. ≈6 pieces).

3. TECHNOLOGICAL PROCESS DESIGN of SLEEVE MACHINING

3.1. ANALYSIS of SLEEVE MACHINING ADAPTABILITY

The part (blank) is made of steel 40X (0.40 % of carbon C, Cr – 1%, sulfur S < 0.09 %; phosphorus P < 0.035 %), therefore blank (production) can be obtained in different ways and shapes: by hot or cold rolling, stamping (punching), forging, casting; rod. The part has large difference of diameters, which not allow using rod as a blank and thus the use of casting or punching techniques for mass and business lot production. But punching technique in steel production is more preferable (in order to avoid cavities in the body of the blank).The material structure is more uniform and that is why we would use forged or stamped blank.

The preliminary processing of external surfaces is made on a lathe machine tool, a key slot 8H9 on the conical surface – on a vertical-milling machine tool with use of a special attachment with clamping on V-block with a pneumonic drive, the machining of the thread M20-8g – by a die on the lathe.

The conical surface with conicity C=1:10 should be preliminary machined on a DNC lathe machine tool.

The final processing should be made on grinding machine tools, as the sizes Ø30g6 and Ø40t7 should be executed with the close tolerance (with the sixth and seventh grade of tolerance) and with a small roughness of surfaces (Ra≤0.8 and 1.25 microns). The conical surface with conicity C=1:10 should be made on grinding machine tool.

The end faces of the part should be machined by turning, since the length of the shaft 220h14 (note: high accuracy is not required).

The shape of the part is convenient for manufacturing. The processing of the external surfaces should be machined in rough and semi-finish operations. It is also necessary to use centre holes in order to obtain a higher accuracy of the radial palpitation surfaces Ø30g6 , Ø40t7, the conical surface with conicity C=1:10 (tolerance is 0.02 mm) and easy to clamp the shaft. The shaft is machined between two centers; thereafter centre holes are drilled in the first and second operations.

The configuration of the part provides easy_removal of chips. This type of a blank allows producing the part by processing it in the universal self-centering 3-jaw chuck for the rough (draft) operations and in collet chuck or on self-centering mandrel with expansion bushing - in finishing operations. The application of exact attachments at final processing is necessary in connection with the close-off tolerance (0.05 mm) of radial palpation of the external cylindrical surface Ø30g6 and 40t7 relative to conical surface.

The application of thermal operation requires. Material (steel 40X) allows to carry out quenching with the specified hardness (it is better to use steel 40X for reduction of required speed of cooling and the possibility of warp of the part). Final processing of surfaces with the exact sizes (Ø30g6, 40t7 and the conical surface C=1:10) should be carried out after thermal operation for the elimination of the possibility of warp of the part. Thus for the final processing, sufficient stock (allowance) should be left in the point of view of a part warping.

3.2. STEPS OF TECHNOLOGICAL DESIGN

The designing of technological processes (TP) of machining begins with the study of service purpose of the part, its technical requirements, and norms of accuracy and program of release, analysis of an opportunity of the enterprise on processing the given part.

The designing of TP represents a multi alternative task, the correct solution of which requires the realization of a number of calculations. Before beginning the designing of kinds of processing of blank surfaces and methods of achievement of their accuracy appropriate to the requirements of the drawing, the type of manufacturing equipment existing at the shop must be defined or established.

For low accuracy initial blanks, TP begins with rough processing of surfaces having greatest stocks. Stocks are removed in first turn from those surfaces on which the defects are possible. This is done for the purpose of the prompt elimination of spoilage.

The step is further designed with a principle of processing at first rough, and then more exact (accurate) surfaces. The most exact surfaces are processed in last turn.

At the end of the step, the minor operations (drilling of small holes, threading and tapping, removal (manufacturing) of chamfers, burring etc.) are also carried out. The easily damaged surfaces are processed at the final stage of TP.

At the requirement of the part quenching all minor surfaces are necessarily processed finally before the quenching, exact surfaces - previously, but they are not rougher than ninth grade of tolerance, saving stocks for final processing. The final processing of surfaces with the exact sizes is made after thermal operations.

For the considered part ("shaft") during the first operation, the surface of the shaft Ø40t7 should be processed, because it will be the base surface for the subsequent operation. Since it is required to supply accuracy of mutual arrangement to surfaces Ø30g6 and conical surface C=1:10, during the second operation it is necessary to use a self-centering chuck with center of a right side.

For increase of accuracy of the positioning of preliminary drilling of blank in the first operation at first it is required to process an end face of blank and to drill a center hole.

For drawing up of a TP route it is required previously to define the processing quantity of each surface. For this purpose, it is better to take the surface with the most exact size and to make a sequence of processing. Thus stocks are consecutive "covered" on the final (design) size, which allows us to receive the intermediate technological sizes. In our task the most exact external size is Ø30h7. It should be processed with 7th grade of tolerance, before - with 9th grade of tolerance, and earlier - with 11th grade of tolerance. We begin to write down the technological sizes from the end (design size is written first) and we go from the right hand to the left, for example: 34.78h12 → 32.68h9 → 31.08h7 → 30g6.

If it is necessary to carry out heat treatment (quenching, tempering and so on) we shall write the route of processing:

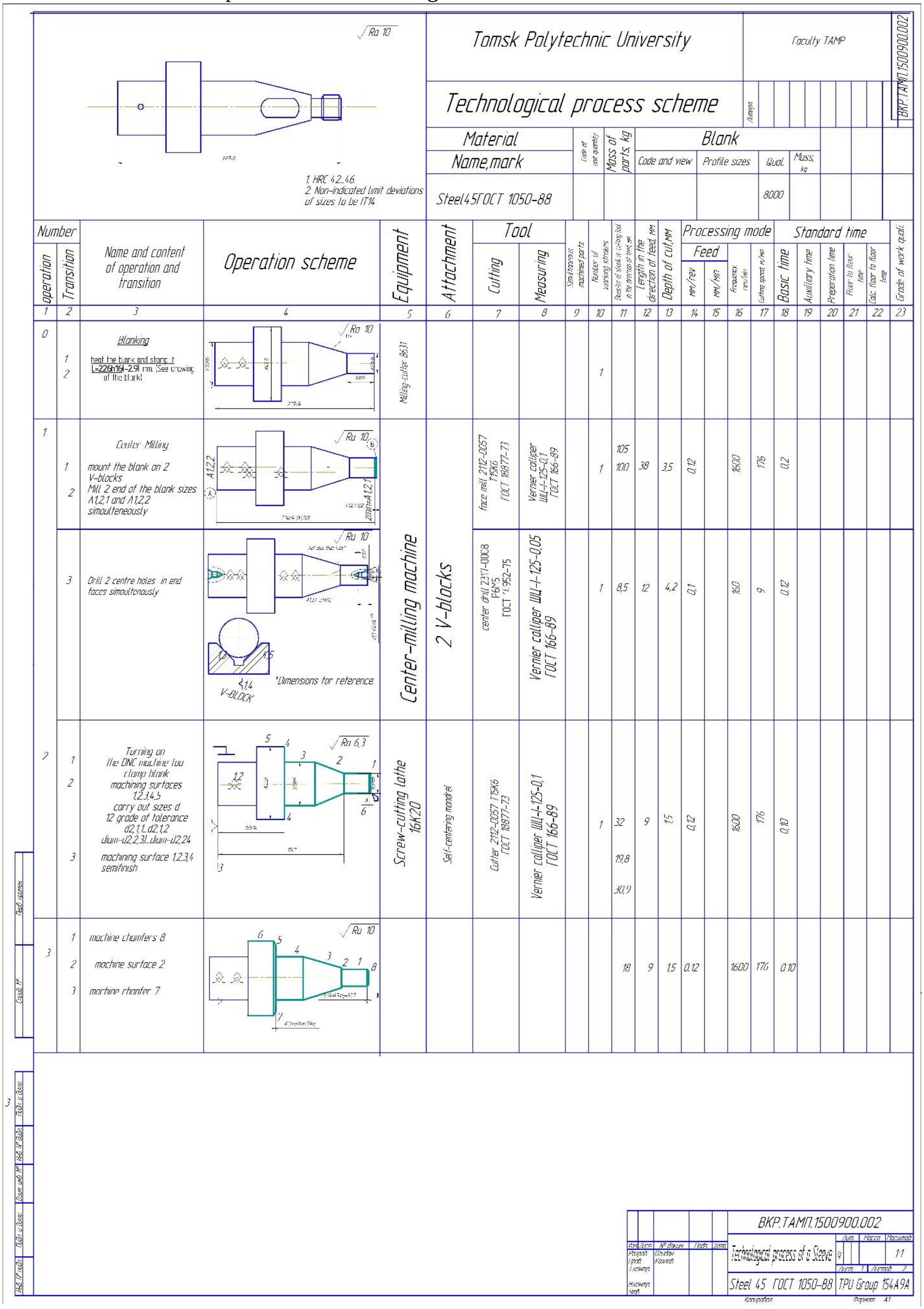
35h16 → 31.13h11 → 30.48h9 → Heat treatment → 30h7.

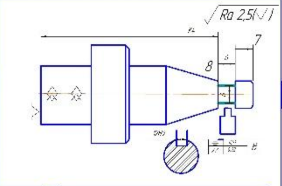
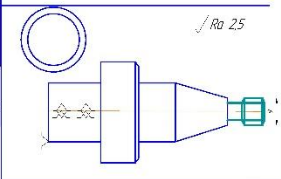
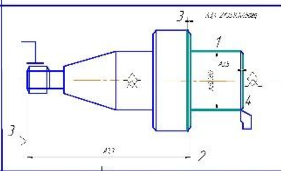
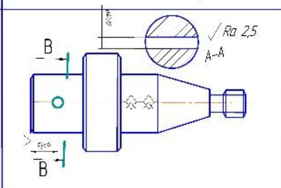
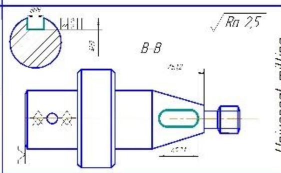
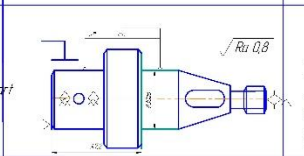
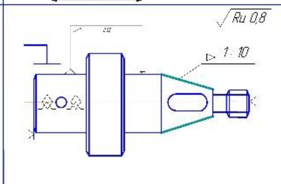
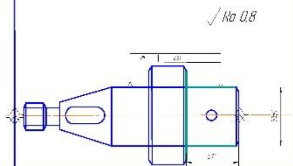
$2Z_{min}$ = 1.8 mm $2Z_{min}$ = 0.4 mm $2Z_{min}$ = 0.32 mm

Such sequence allows avoiding one operation (before heat treatment with 9th grade of tolerance), however it can result in the increase of the possibility of the occurrence of a spoilage and hence, increase in the cost price of the part manufacturing.

In tab. 3.1 at first we write down a sequence of processing and operational sketches, but we shall calculate values of the intermediate technological sizes later, after the calculation of minimal stocks of processing (tab. 4.1). In operational sketches we shall write intermediate technological sizes approximately at first. Then we shall write a new table of the technological route where we shall write only definitive technological sizes.

Table 3.1. Route of the part "shaft" machining



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	4 5 6 7	Turn surface to create a ridge between shaft and the thread head with a diameter of h16,14...di-(0,5...1)mm and round the edges turn surface of chamfer 7 A2,6=2js14x45deg turn surface of chamfer 8		Thread-cutting(die) lathe 16K20	Self-centering mandrel	Cutter 2102-0055 T5K6 ГОСТ 18877-73	Micrometre MK50-1 ГОСТ 6507-90. Templet for chamfer 45°.		1 1	30,5 19,5	51 2,7	0,331 2,7	0,32 0,5		1600 1600	176 176	0,11 0,09				
	4 1 6	Threading Mount and take off part make a thread with a die tool a M20-8g thread 1,				Cutter 2102-0055 T5K6 ГОСТ 18877-73	Micrometre MK50-1 ГОСТ 6507-90. Templet for chamfer 45°.		1	5,0	6,0	2,5	0,15		1900	28,3	0,04				
3	1 2 3 4	turning operation clamp blank Turn surface the other way around to machine d 31,7h12 turn surface 1 and 2 turn chamfer 3 turn chamfer 5		Universal milling machine Ф4251	Special V Block	Two flute End mill	Turn surface the other way around in the second pass(rough)		1	31,1	51	1,95	0,5		1600	176	0,068				
4	1 2	Drilling Mount and take off the part drill key-slot maintaining other sizes		Vertical drilling machine 2H125	Drill jig conductor	Drill Ф5 P6M5 ГОСТ 10903-77	Vernier calliper ШЦ I-125-0,1 ГОСТ 166-89		1	8,0	15,0	8,0	$S_{прод}$ 0,007 мм/об $S_{поп}$ 0,022 мм/об		1000	25,12	0,375				
4	1 2	milling Mount and take off the part Mill key-slot maintaining other sizes		Universal milling machine Ф4251	Special V Block	Two flute End mill	Vernier caliper ШЦ I-125-0,1 ГОСТ 166-89		1	8,0	15,0	8,0	$S_{прод}$ 0,007 мм/об $S_{поп}$ 0,022 мм/об		1000	25,12	0,375				
5	1 2	Heat treatment Quenching Annealing the part to HRC 42...46																			
6	1 2	Cylindrical grinding Mount and remove the part Grind surface 1		Cylindrical grinder 3Е12	Self centering mandrel	ПП 200х10х32 22А 40 СМ2 К5 6 ГОСТ 2424-83	Micrometre MK50-1 ГОСТ 6507-90.		11	30	50,5	0,331	S_t мм/об		2350	168,3(28м/с)	0,225				
7	A 1	cylindrical grinding Mount part Grind surface 1		Surface grinding lathe 3Е710А	Electromagnetic table	ПП 200х32х76 22А 40 СМ2 К5 6 ГОСТ 2424-83	Vernier caliper ШЦ-I-125-0,05 ГОСТ 166-89		13	Ф200	30,5	0,5	S_t мм/об		1670	104,8 (17,5м/с)	0,832				
8	B 2	Mount and remove part Grind surface 2					Micrometre MK50-1 ГОСТ 6507-90.		11	Ф200	30,5	0,436	$S_{поп}$ мм/об		1670	104,8 (17,5м/с)	0,704				
9		metal working Control Control the size and the surface roughness according to the requirements of the drawing																			

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4. CALCULATION of ALLOWANCES

Stock (allowance) is a layer of a material, removed in machining. Its minimal thickness Z_{min} depends on many factors, but the major ones are:

1. Roughness of the surface received from previous machining (index i-1) - Rz $i\text{-}_1$;
2. Thickness of defective layer of the surface received from previous machining - Tdef $i\text{-}_1$;
3. Curvature (warp) of the surface received from previous machining - ρ $i\text{-}_1$;
4. Error of basing and fastening received at considered machining (index i) - εi.

If stock is less minimal, the traces from the previous machining will stay, which is not allowable. Stock is removed per one or several cuts, if the thickness is too large.

Minimal stock for considered machining (operation) is defined from the tables or calculated by the formulas, where we can calculate minimal stock taking into account the seldom probability of occurrence in the same direction of warp of a surface received from previous machining ($\rho_{i\text{-}1}$) and error of basing and fastening received at considered machining (ε_i) for rotation surfaces:

$$2z_{\min.i} = 2\cdot\left(R_{z.i-1} + T_{\partial.i-1} + \sqrt{(\rho_{i-1}^2 + \varepsilon_i^2)}\right), \qquad (4.1)$$

Where $2z_{min\ i}$ is a minimal stock of rotation surfaces for considered machining.

It is better to calculate minimal stock taking into account the probability of occurrence in the same direction of warp of a surface received at the previous manufacturing ($\rho_{i\text{-}1}$) and error of basing and fastening received at considered manufacturing (ε_i) for rotation surfaces:

$$2z_{\min.i} = 2\cdot\left(R_{z.i-1} + T_{\partial.i-1} + \rho_{i-1} + \varepsilon_i\right), \qquad (4.2)$$

For flat surfaces (non-rotating surfaces) minimal stock is calculated by the formula:

$$z_{min\ i} = Rz_{\ i\text{-}1} + T_{def\ i\text{-}1} + \rho_{\ i\text{-}1} + \varepsilon_{\ i}. \qquad (4.3)$$

4.1. Stock calculation for the surface processing Ø40t7

We make stock calculations of the surface processing Ø40t7 by drawing up of tab. 4.1, in which the technological route of the surface processing and all values of stock elements are written consistently.

Total value Rz and Tdef, describing quality of a surface of blank from cold rolling process, is determined from tab. 27 [4, page 66]. For each subsequent technological transition these values are determined from tab. 29 [4, page 67].

We determine total deviation of a warp error ρ_{warp} and displacement ρ_{dis} by the formula:

$$\rho = \sqrt{(\rho_{dis}^2 + \rho_{warp}^2)}\ , \qquad (4.3)$$

Where: ρ_{dis} - error of blank on displacement concerning an axis in a radial direction; ρ_{warp} - error of blank on warp.

We find size of a residual spatial deviation of a blank for a surface processing Ø30h7.
The error of blank on displacement is defined from tab. 32 [4, page 72]:
ρ_{dis}= 0.360 mm = 360 μm.
The blank error of a warp is defined by product of length of blank ℓ on specific warp Δ_w, which depends on the method of blank manufacturing on the previous operation:

$$\rho_{warp} = \Delta_w \times \ell = 0.12 \times 60 = 7.2 \ \mu m,$$

Where specific warp Δ_w is defined from tab. 32 [4, page 72].

Total deviation of an error on warp and displacement:

$$\rho_0 = \sqrt{(360^2 + 7.2^2)} = 360.4 \mu m \approx 360 \ \mu m.$$

Residual spatial deviation of the blank ρ_0 =360 microns.

After that we find value of a residual spatial deviation after preliminary turning (rough turning) using the factor of residual warp k_{warp} and warp of blank ρ_{blank}: $\rho_1 = k_{warp} \times \rho_{blank} = 0.08 \cdot 360 = 30 \mu m$.

Residual spatial deviation after semi-finish (fair) turning:

$$\rho_2 = k_{warp} \times \rho_{blank} = 0.02 \cdot 360 = 7{,}2 \approx 10 \ \mu m.$$

Residual spatial deviation after grinding: $\rho_3 = k_{warp} \times \rho_{blank} = 0.1 \cdot 50 = 5 \ \mu m$.

Table 4.1. Calculation of stocks and limit technological sizes for technological transitions for surfaces manufacturing

Technological transitions	Elements of stock, μm				Calculated stock, $2z_{min}$,μm	Calculated size d_c, mm	Tole-rance T, μm	Limit sizes, mm	
	R_Z	T	ρ	ε				d_{min}	d_{max}
External surface ($Ø\mathbf{40}t7(^{+0,073}_{+0,048})$)									
Hot stamped (h16)	*160*	*150*	*360*	---		*44h16*	1600	42.34	43.94
Turning:									
rough (h11)	*40*	*40*	*30*	*100*	2*770	40.8h11	160	40.64	40.8
semifinish (h9)	*10*	*10*	*10*	*10*	2*120	40.4h9	62	40.333	40.395
Heat Treatment HRC 42…46	*20*	*50*	*50*	---	–				
grinding (t7)	*6*	*6*	*5*	*10*	2*130	40t7	**25**	40.048	40.073
Eternal surface (shaft) $\mathbf{Ø30}\boldsymbol{g6}(^{-0.007}_{-0.02})$									
Hot stamped (h16)	*160*	*150*	*360*	---		34h16	*1600*	32.44	34.04
Rough turning (h11)	*40*	*40*	30	*100*	2*770	30.9h11	160	30.74	30.9
Semi-finish(h9)	*10*	*10*	*10*	*10*	2*120	30.5h9	62	30.36	30.422
Heat Treatment HRC 42…46	*20*	*50*	*50*	---	–				
Rough round grinding (h7)	*6*	*6*	*5*	*10*	2*130	30.1h7	25	30.037	30.062
Finish round grinding (g6)	*3.2*	*4*	*3*	*5*	2*22	30g6	13	29.98	29.993

External surface (length of shaft) **220h14**($_{-1.15}$)									
Stamped blank (side B) (h16)	*160*	*250*	*350*	---	–	225.8h16 (from unprocessed surface B to unprocessed surface A)	2.9	222.88	225.78
Mill side B (h14)	*40*	*40*	*21*	120	880	**222.0 h14** (from unprocessed surface B to processed surface A) (already calculated)	~~1.150~~	~~220.88~~ (already calculated)	~~222.03~~ (already calculated)
Stamped blank (side A) (h14)	*160*	*250*	*350*	-	–	222.0 h14 (from unprocessed surface B to processed surface A)	1.150	220.88	222.03
Mill side A (h14)	*40*	*40*	*21*	120	880	220h14 (between processed surfaces A & B)	1.150	218.85	220.0

As the blank is maintained on a self-centering mandrel, we shall define an error of installation by the formula:

$$\varepsilon_i = \sqrt{(\varepsilon_b^2 + \varepsilon_f^2)} = \varepsilon_f = 100\mu m,$$

Where an error of basing $\varepsilon_b \to 0$ (since at installation of the blank in the attachment the technological base coincides with design base); ε_f *is* an error of fastening (clamping).

For the part "shaft" minimal stocks are determined by the equation (4.1) for processing a surface Ø**40**t7$\left(^{+0,073}_{+0,048}\right)$:

- for the preliminary turning (with 11th grade of tolerance):

$$2z_{\min.i} = 2\cdot\left(R_{z.i-1} + T_{\partial.i-1} + \sqrt{(\rho_{i-1}^2 + \varepsilon_i^2)}\right) = 2\cdot\left(160 + 150 + \sqrt{(360^2 + 100^2)}\right) = 1840\ \mu m$$

- for the semi-finish (fair) turning (with 9th grade of tolerance):

$$2z_{\min.i} = 2\cdot\left(40 + 40 + \sqrt{(30^2 + 10^2)}\right) = 369\ \mu m;$$

- for the grinding (with 7th grade of tolerance):

$$2z_{\min.i} = 2\cdot\left(20 + 50 + \sqrt{(50^2 + 10^2)}\right) = 68.3\ \mu m.$$

It is better for us to take into account the small scale manufacturing of the part and for increasing of manufacturing reliability we shall calculate minimal stock (allowance) of surface Ø40t7 by the formula (4.2) taking into account the probability of occurrence in the same direction of warp (ρ_{i-1}) and error of basing and fastening (ε_i) for rotation surfaces:

- for the preliminary turning (with 11 grade of tolerance):

$$2z_{\min.i} = 2\cdot\left(R_{z.i-1} + T_{\partial.i-1} + \rho_{i-1} + \varepsilon_i\right) = 2\cdot(160+150+360+100) = 2\times 770 = 1540\ \mu m;$$

- for the semi-finish (fair) turning (with 9 grade of tolerance):

$$2z_{\min\ i} = 2\cdot(40 + 40 + 30 + 10) = 2\times 120 = 240\ \mu m;$$

- for the grinding (with 7 grade of tolerance):

$2z_{min\ i} = 2(20 + 50 + 50 + 10) = 2\times130 = 260$ µm.

Results of calculations by the formula (4.2) are written in tab. 4.1.

4.2. Stock calculations for a surface $Ø30g6(^{-0.007}_{-0.02})$

We do calculations of processing stocks for a surface $Ø30g6(^{-0.007}_{-0.02})$by drawing up of tab. 4.1, in which the technological route of a surface processing and all values of stock elements are written consistently. Total values Rz and T_{def}, describing quality of a cold rolling blank surface are determined with the help of tab. 27 [4, page 66]. For each subsequent technological transition these values are determined using tab. 29 [4, page 67].

We determine total deviation of a warp error ρ_{warp} and displacement ρ_{dis} by the formula (4.3):

$$\rho = \sqrt{(\rho_{dis}^2 + \rho_{warp}^2)},$$

Where: ρ_{dis} - error of blank on displacement concerning an axis in a radial direction; ρ_{warp} - error of blank on warp.

The error of blank on displacement is defined from tab. 32 [4, page 72]:

ρ_{dis}= 0.5 mm = 500 µm.

The blank error of a warp is defined by product of length of blank ℓ on specific warp Δ_w, which is dependent on the method of blank manufacturing in the previous operation:

$$\rho_{warp} = \Delta_w \times \ell = 0.12\times52 = 6.24 \text{ µm},$$

Where specific warp Δ_w is defined from tab. 32 [4, page 72].

Total deviation of an error on warp and displacement:

$$\rho_0 = \sqrt{(350^2 + 6.24^2)} \approx 360\mu m$$

Residual spatial deviation of blank ρ_0 =360 µm.

We find size of a residual spatial deviation for a have processed surface with 11 grade of tolerance

$$\rho_1 = \sqrt{C_0^2 + (\Delta_b \cdot L)^2} = \sqrt{2.5^2 + (0.6 \cdot 50)^2} \approx 30 \text{ µm}.$$

As the blank is maintained between centers, we shall define the error of installation by the formula:

$$\varepsilon_i = \sqrt{(\varepsilon_b^2 + \varepsilon_f^2)} = \varepsilon_f = 100\mu m,$$

Where an error of basing $\varepsilon_b \rightarrow 0$ (since at installation of blank in the attachment the technological base coincides with design base); ε_f *is* an error of fastening (clamping).

Minimal stocks for processing the surface $Ø30g6(^{-0.007}_{-0.02})$ are calculated by the equation (4.2) for increasing of manufacturing reliability:

4.3. Stock calculations for a surface 220h14

We make calculations of processing stocks by the formula (4.3) for a surface 220h14 ($_{-1.15}$) by drawing up of tab. 4.1, in which the technological route of the surface processing and all values of stock elements are written consistently.

It is better to define warp of a surface received at the previous manufacturing (ρ_{i-1}) and error of basing and fastening received at considered manufacturing (ε_i) from machinist handbook. We shall write these values in formula (4.3):

- for the preliminary turning of right face end of the blank (with 14 grade of tolerance):

$$z_{min\ i} = Rz_{i-1} + T_{def\ i-1} + \rho_{i-1} + \varepsilon_{i}. = 160 + 250 + 350 + 120 = 880\ \mu m;$$

Results of accounts by the formula (4.3) are written in tab. 4.1.

4.4. Calculation of technological sizes

4.4.1. Calculation of technological sizes for machining Ø40h14

We make calculations of technological sizes with the help of size circuit analyses. We draw sizes circuits for the Ø30h7 ($_{-0.021}$) (Fig. 4.1). Technological size A_3 has to be equal (by rough calculation) to design size K. Sometimes technological size coinciding with design size has to be more accurate (with less grade of tolerance but with the same fundamental deviation) if it is necessary to solve size circuit. This size A_3 is processed in second technological transition of sixth operation, and that is why we can mark it by symbol $A_{6.2.}$ We can write: A_3 = K = $A_{6.2}$ = Ø30h7 ($_{-0.021}$).

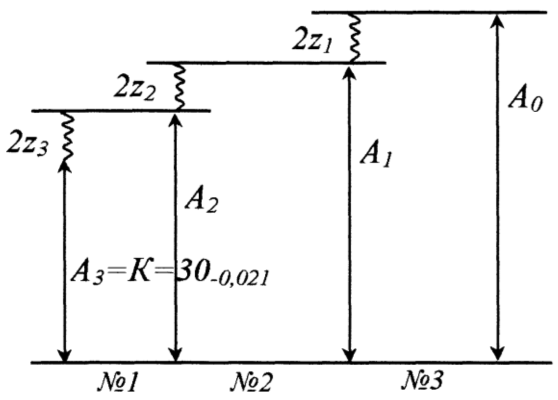


Fig. 4.1. Sizes circuits for calculations of technological sizes for processing external surface **Ø30h7**

Here and further we shall write technological size with index, which shows number of technological operation (first figure) and number of technological transition (second figure) were this technological size is processed. For example, technological size $A_{6.2}$ is processed in sixth operation and in second technological transition (in second technological transition of sixth operation).

Stock $2z_3$ in size circuit №1 is equal to $2z_{6.2}$: $2z_3 = 2z_{6.2}$.

Here and further we shall write stock of technological size with index, which shows number of technological operation (first figure) and number of technological transition (second figure) where this stock is removed (where the technological size with the same index is processed). For example, stock $2z_{6.2}$ is removed in sixth operation and in second technological transition (in second technological transition of sixth operation), were technological size $A_{6.2}$ is processed.

1. We shall find technological size A_2 using size circuit №1:

$2z_{3min} = A_{2min} - A_{3max}$;

From which we shall calculate minimal technological size A_{2min}:

$A_{2min} = A_{3max} + 2z_{3min} = A_{5.2max} + 2z_{5.2min} = = 30 + 0.08 = 30.08$ mm;

$A_{2max} = A_{2min} + TA_2 = 30.08 + 0.062 = =30.142$ mm,

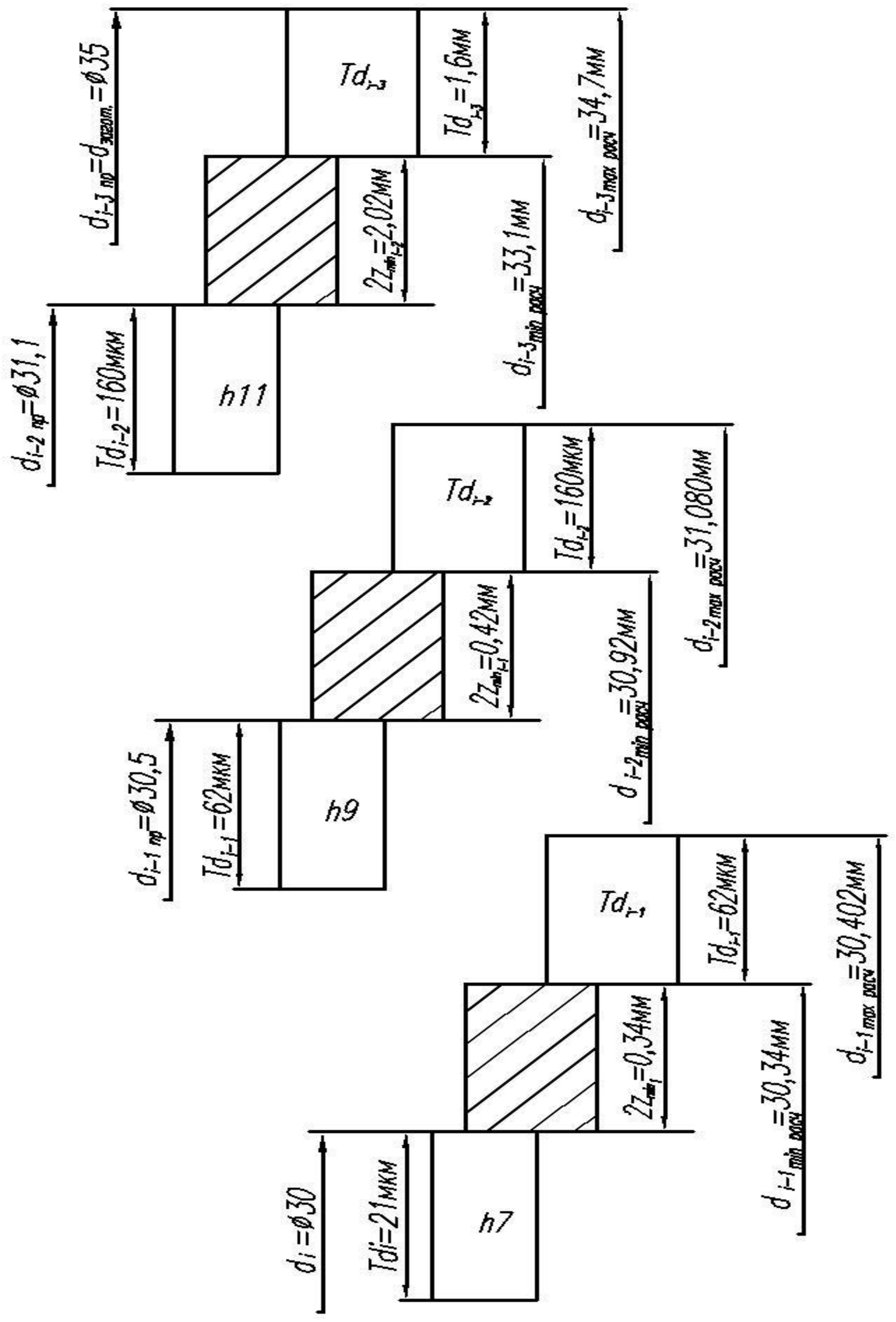


Рис. 4.2. Поле припусков и допусков технологических размеров при обработке ***наружной*** поверхности **Ø30h7**

Where TA_2 = IT9 = 62 µm = 0.062 mm – in accordance with technological route of size Ø30h7 processing (see tab. 3.1 and tab. 4.1). We find minimal stock ($2z_3 = 2z_{6.2}$) in tab. 4.1.
Calculated (previous determined) technological size A_2 is:
$A_{2cal} = 30.142_{-0.062}$ mm – after finish turning.

We round the base (nominal) size in greater value (as a "shaft") with tenth of millimeter accuracy:
$A_{2acc} = A_{2.4} = Ø30.2h9(_{-0.062})$ mm – is preliminarily (by rough calculation) accepted technological size A_2 which is obtained after finish turning (with 9 grade of tolerance) in fourth technological transition of second operation.
$A_{3acc} = K = A_{6.2} = Ø30h7\ (_{-0.021})$ mm – is preliminarily (by rough calculation) accepted technological size A_3 which is obtained after round grinding (with 7th grade of tolerance) in second technological transition of sixth operation.
2. We shall find technological size A_1 using size circuit №2:
$2z_{2min} = A_{1min} – A_{2max}$;
$A_{1min} = A_{2max} + 2z_{2min} = 30.2 + 0.42 = 30.62$ мм;
$A_{1max} = A_{1min} + TA_1 = 30.62 + 0.16 = 30.78$ мм;
$A_{1cal} = 30.78_{-0.16}$ mm – after rough turning.
We round the base size in greater value (as a "shaft") with tenth of millimeter accuracy:
$A_{1acc} = A_{2.3} = Ø30.8h11(_{-0.16})$ mm – is preliminarily (by rough calculation) accepted technological size A_1 which is obtained after rough turning (with 11th grade of tolerance) in third technological transition of second operation.
3. We shall find technological size A_0 (diameter of a blank) using size circuit №3:
$2z_{1min} = A_{0min} – A_{1max}$;
$A_{0min} = A_{1max} + 2z_{1min} = 30.8 + 2.02 = 32.82$ mm;
$A_{0max} = A_{0min} + TA_0 = 32.82 + 1.600 = 34.42$ mm;
$A_{0cal} = 34.42\ _{-1.6}$ mm.
We accept $A_0 = A_{02} = Ø35h16(_{-1.6})$ mm – is preliminarily (by rough calculation) accepted diameter of the blank in accordance with standard for diameter of cold rolling production.
We recalculate stock:
$2z_{1min} = A_{0min} – A_{1max} = 33.4 – 30.8 = 2.6$ mm;
$2z_{1max} = A_{0max} – A_{1min} = 35 – 30.64 = 4.36$ mm.
Depth of cut for calculation of cutting speed is calculated by the formula: $t = 2z/2$.
That maximal depth of cut (it is necessary to calculate maximal cutting force for calculation of clamping force of attachment) $t_{max} = 2z_{max}/2 = 4.36 / 2 = 2.18$ mm.
Minimal depth of cut: $t_{min} = 2z_{min}/2 = 2.6 / 2 = 1.3$ mm;
Average depth of cut (it is necessary to calculate cutting speed):
$t_{av} = (t_{max} + t_{min})/2 = (2.18 + 1.3) / 2 = 1.741$ mm.

Further we shall not recalculate stock and depth of cut because we shall define more precisely technological sizes (after size analysis of technological process).

4.4.2. Calculation of technological sizes for processing Ø20H7

We draw sizes circuits for the hole Ø20H7 ($^{+0.021}$) processing (fig. 4.2).

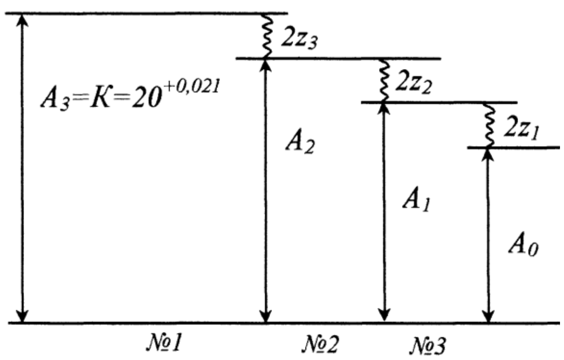


Fig. 4.2. Sizes circuits for calculations of technological sizes for processing internal surface **Ø20H7**

Technological size A_3 has to be equal (*by rough calculation*) to design size *К*. We can write: $A_3 = К = A_{8.2} =$ $= 20H7 (^{+0.021})$.

1. We shall find technological size A_2 using size circuit № 1:

$2z_{3min} = A_{3min} – A_{2max}$;

$A_{2max} = A_{3min} - 2z_{3min} = 20 - 0.302 =$ $=19.698$ мм;

$A_{2min} = A_{2max} - TA_2 = 19.698 - 0.13 =$ $=19.568$ мм;

$A_{2cal} = 19.568^{+0.13}$ mm – after boring.

We round the base size in smaller *(*lesser*)* value (as a “hole”) with tenth of millimeter accuracy:

$A_{2acc} = A_{1.5} = Ø19.5H11 (^{+0.13})$ mm – is preliminarily (by rough calculation) accepted technological size $A_{1.5}$ which is obtained after boring (with 11 grade of tolerance) in fifth technological transition of first operation.

$A_{3acc} = К = A_{8.2} = Ø20H7(^{+0.021})$ mm - is preliminarily (by rough calculation) accepted technological size A_3 (final) which is obtained after internal grinding (with 7 grade of tolerance) in second technological transition of eighth operation.

2. We will find technological size A_1 using size circuit № 2:

$2z_{2min} = A_{2min} – A_{1max}$;

$A_{1max} = A_{2min} - 2z_{2min} = 19.5 - 2.572 = 17.928$ mm;

$A_{1min} = A_{1max} - TA_1 = 17.928 - 0.43 = 17.498$ mm;

$A_{1cal} = 17.498\ ^{+0.43}$ mm – after drilling of hole.

We round the base size in slightly greater value (as the decreasing of minimal stock on 0.002 mm is not sufficient for rough drilling) with tenth of millimeter accuracy:

$A_{1acc} = A_{1.4} = 17.5H14(^{+0.43})$ mm – is preliminarily (by rough calculation) accepted technological size A_1 which is obtained after drilling of hole (with 14 grade of tolerance) in fourth technological transition of first operation.

3. We can find technological size A_0 (diameter of a blank hole) using size circuit №2 (but it is not need, because we drill a hole in blank without piercing hole):

$2z_{1min} = A_{1min} – A_{0max}$;

$A_{0max} = A_{1min} - 2z_{1min} = 17.5 – 2.02 = 15.48$ mm;

$A_{0min} = A_{0max} - TA_0 = 15.48 - 1.1 = 14.38$ mm,

Where $TA_0 = IT16 = 1100$ μm = 1.1 mm – tolerance of pierced hole (with 16th grade of tolerance.)

A_{0cal} = 14.38$^{+1.1}$ mm (if the blank has a hole, for example, by piercing in forging process.)
We accept the hole diameter in the blank $A_{0acc} = A_0$ = Ø14.3H16 ($^{+1.1}$) mm (only in case if the blank enter into production with previously pierced hole.)

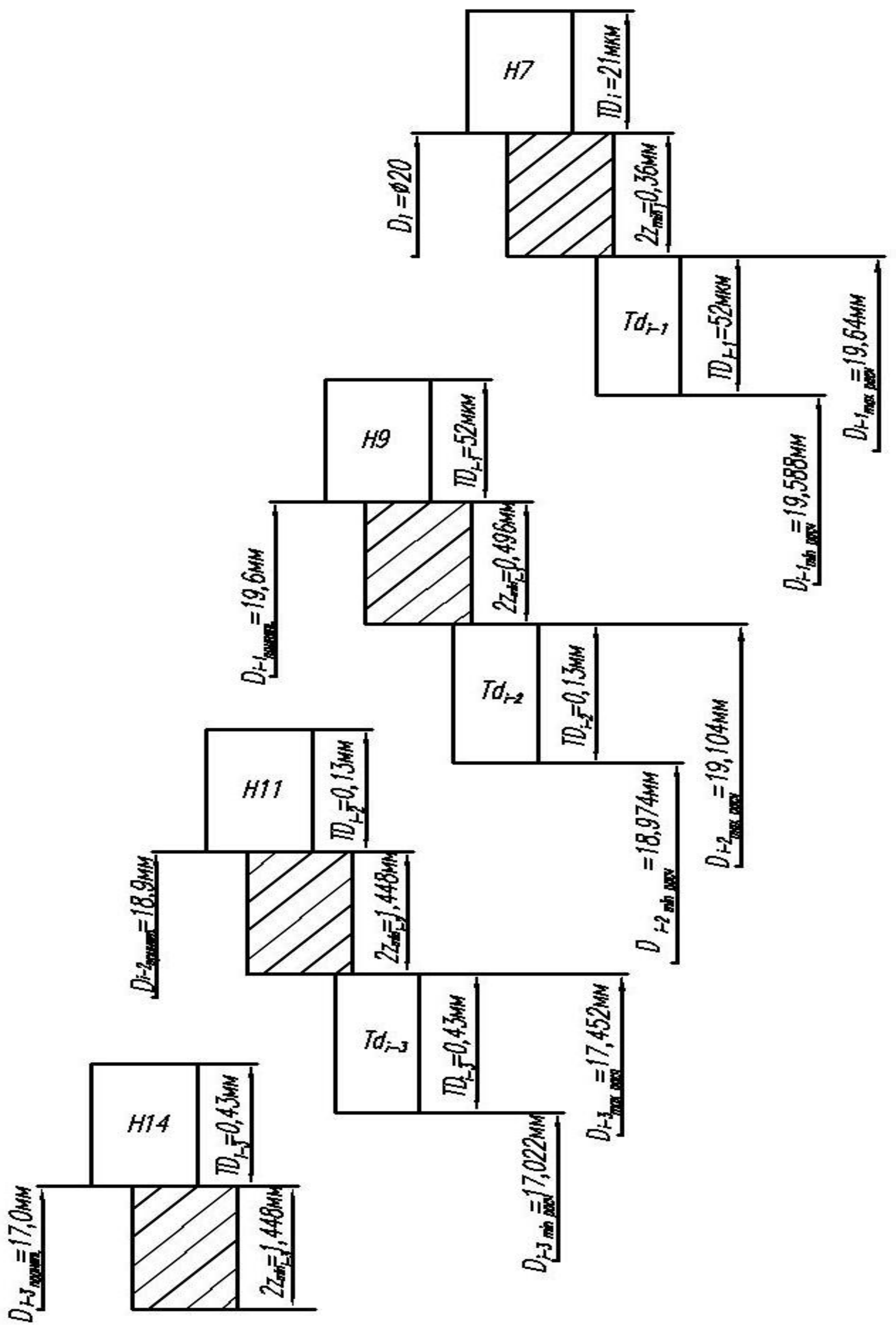


Fig. 4.3. Fields of allowances and tolerances of technological dimensions for machining internal surface (hole) **Ø20H7**

4.4.3. Calculation of technological sizes for machining length 50h9 of shaft

We draw sizes circuits for processing of detail on length with size 50h9 ($_{-0.062}$) (fig. 4.4). Technological size A_4 has to be equal (*by rough calculation*) to design size K_1. We can write: $A_4 = K_1 = A_{7.2} = 50h9(_{-0.062})$.

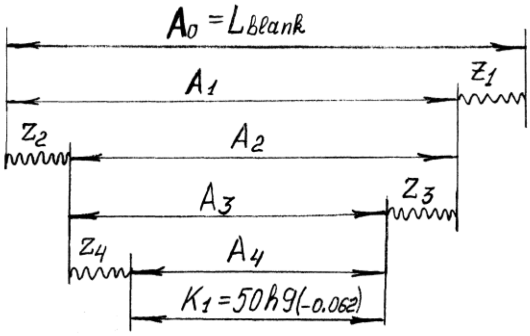


Fig. 4.4. Sizes circuits for calculations of technological sizes for processing of detail on length with size **50h9**

1. We will find technological size A_3 using size circuit №1:

$z_{4min} = A_{3min} – A_{4max}$;

or: $z_{4min} = A_{3min} – K_{1max}$;

$A_{3min} = K_{1max} + z_{4min}$=50+0.154=50.154 mm;

$A_{3max} = A_{3min} + TA_3$ = 50.154 + 0.190 = =50.344 мм,

where TA_3 = 0.190 mm (tolerance of 9 grade of tolerance for the interval from 50 mm to 80 mm – for the size more than 50 mm in table of tolerances.)

$A_{3cal} = 50.344_{-0.19}$ mm – after grinding of right face side of sleeve.

We round the base size in greater value (as a “shaft”) with tenth of millimeter accuracy:

$A_{3acc} = A_{7.1} = 50.4h11(_{-0.19})$ mm – is preliminarily (by rough calculation) accepted technological size A_3 which is obtained after grinding of right face side of sleeve (with 11th grade of tolerance) on second technological transition of seventh operation.

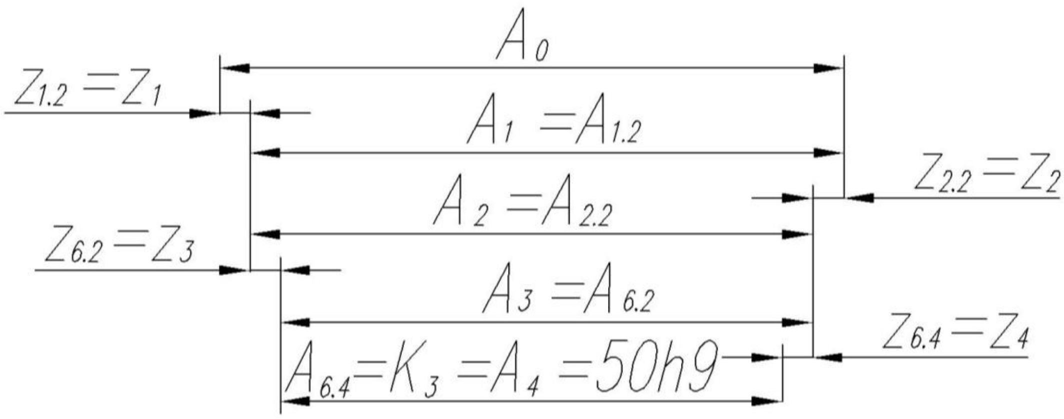


Fig. 4.5. Sizes circuits for calculations of technological sizes for processing of detail on length with size **50h9**

2. We shall find technological size A_2 using size circuit №2:

$z_{3min} = A_{2min} – A_{3max}$;

$A_{2min} = A_{3max} + z_{3min}$ = 50.4 + 0.178 = 50.578 mm

$A_{2max} = A_{2min} + TA_2$ = 50.578 + 0.740 = 51.318 mm

where TA_2 = 0.740 mm (tolerance of 14th grade of tolerance for the interval from 50 mm to 80 mm – for the size more than 50 mm in table of tolerances.)
$A_{2\ cal} = 51.318_{-0.74}$ mm.

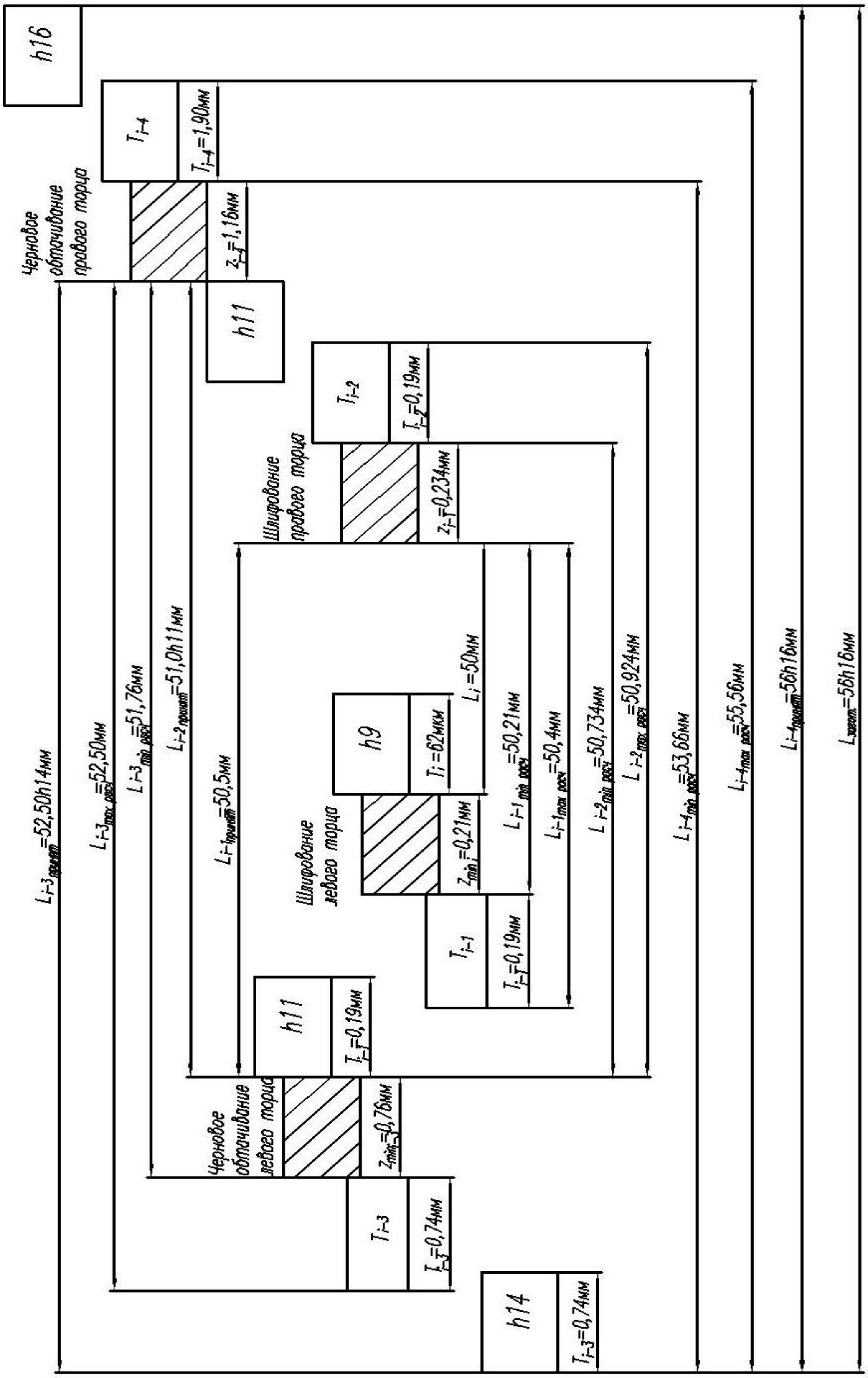


Fig. 4.6. Sizes circuits for calculations of technological sizes for machining of detail on length with size **50h9**

$A_{2\ cal} = 51.318_{-0.74}$ mm.
We round the base size in greater value (as a “shaft”) with tenth of millimeter accuracy:
$A_{2acc} = A_{2.2} = 51.4h14(_{-0.74})$ mm – is preliminarily (by rough calculation*)* accepted technological size $A_{2.2}$ which is obtained after rough turning of left face side of cartridge (with the 14th grade of tolerance) in second technological transition of second operation.
3. We shall find technological size A_1 using size circuit № 3:
$z_{2min} = A_{1min} – A_{2max}$;
$A_{1min} = A_{2max} + z_{2min} = 51.4 + 0.760 = 52.16$ mm;
$A_{1max} = A_{1min} + TA_1 = 52.16 + 0.740 = 52.90$ mm,
where TA_1= 0.740 mm (tolerance of 14th grade of tolerance for the interval from 50 mm to 80 mm – for the size more than 50 mm in table of tolerances.)
$A_{1\ cal} = 52.9_{-0.74}$ mm.
We accept: $A_{1acc} = A_{1.2} = 52.9h14(_{-0.74})$ mm – is preliminarily (by rough calculation) accepted technological size $A_{1.2}$ which is obtained after rough turning of right face side of cartridge (with 14 grade of tolerance) on second technological transition of first operation.
4. We shall find technological size A_0 using size circuit № 3:
$z_{1min} = A_{0min} – A_{1max}$;
$A_{0min} = A_{1max} + z_{1min} = 52.9 + 1.160 = 54.060$ mm;
$A_{0max} = A_{0min} + TA_0 = 54.060 + 1.900 = 55.960$ mm;
where TA_0= 1.9 mm (tolerance of 16th grade of tolerance for the interval from 50 mm to 80 mm – for the size more than 50 mm in table of tolerances.)
$A_{0\ cal} = 55.96_{-1.9}$ mm.
We accept: $A_{0acc} = A_0 = 56h16(_{-1.9})$ mm – is preliminarily (by rough calculation) accepted technological size A_0 (length of blank) which is obtained after cutting off with (by) slitting saw a rod (with 16th grade of tolerance) in zero (blanked) operation.

5. SIZE ANALYSIS of TECHNOLOGICAL PROCESS

The purpose of size analysis consists of the estimation of technological processes quality. We check and correct, if it is necessary, deviations of sizes comparing final technological sizes with design sizes given on the executive (work) drawing. The initial data for the size analysis are:

1. Drawing of the part.
2. Drawing of initial blank.
3. Technological process of the part processing.

We draw general scheme of the part processing and select sizes circuits, into which design sizes are included. Component links (making parts) in technological size circuits are the technological sizes, which are specified in the technological documentation (sizes of initial blank and all sizes obtained at machining). The final technological sizes should coincide with the sizes specified on the drawing, i.e. with the design sizes. If such concurrence is not present, i.e. the technological size does not coincide with design size (design size is not maintained directly), it is necessary to reveal (to define) such size circuit, into which the considered design size and technological sizes are maintained for reception of the design size. Such design size is a closing link, and since it is required to execute it with given base (nominal) size and deviations, it is referred to as initial. Closing links in technological size circuits can be design and technological sizes, and also stocks for processing.

We consistently consider size circuits with one unknown technological size and we consider base value and deviations of this link. If there are several unknown technological sizes, we calculate the tolerances of the unknown sizes (usually by method of equal accuracy), and then we nominate values and deviations of all unknown technological sizes except for one, concerning which the decision will be made.

We draw general scheme of the part processing (fig. 5.1). Then we check the coincidence of final technological sizes with the sizes specified on the drawing.

1. $A_{7.2} = K_1 = 50h9(_{-0.062})$ i.e. design size K_1 is processed directly (enters) in the seventh operation and in the second technological transition by the technological size $A_{7.2}$;

2. K_2, K_3, K_4, K_5, K_6 are not processed directly, that is why it is necessary to reveal (to define) such size circuit, into which the considered design sizes (K_2, K_3, K_4, K_5 and K_6) and technological sizes are maintained for obtaining the design sizes. Those design sizes are closing links, and since it is required to execute them with the given base sizes and deviations, they are referred to as initials.

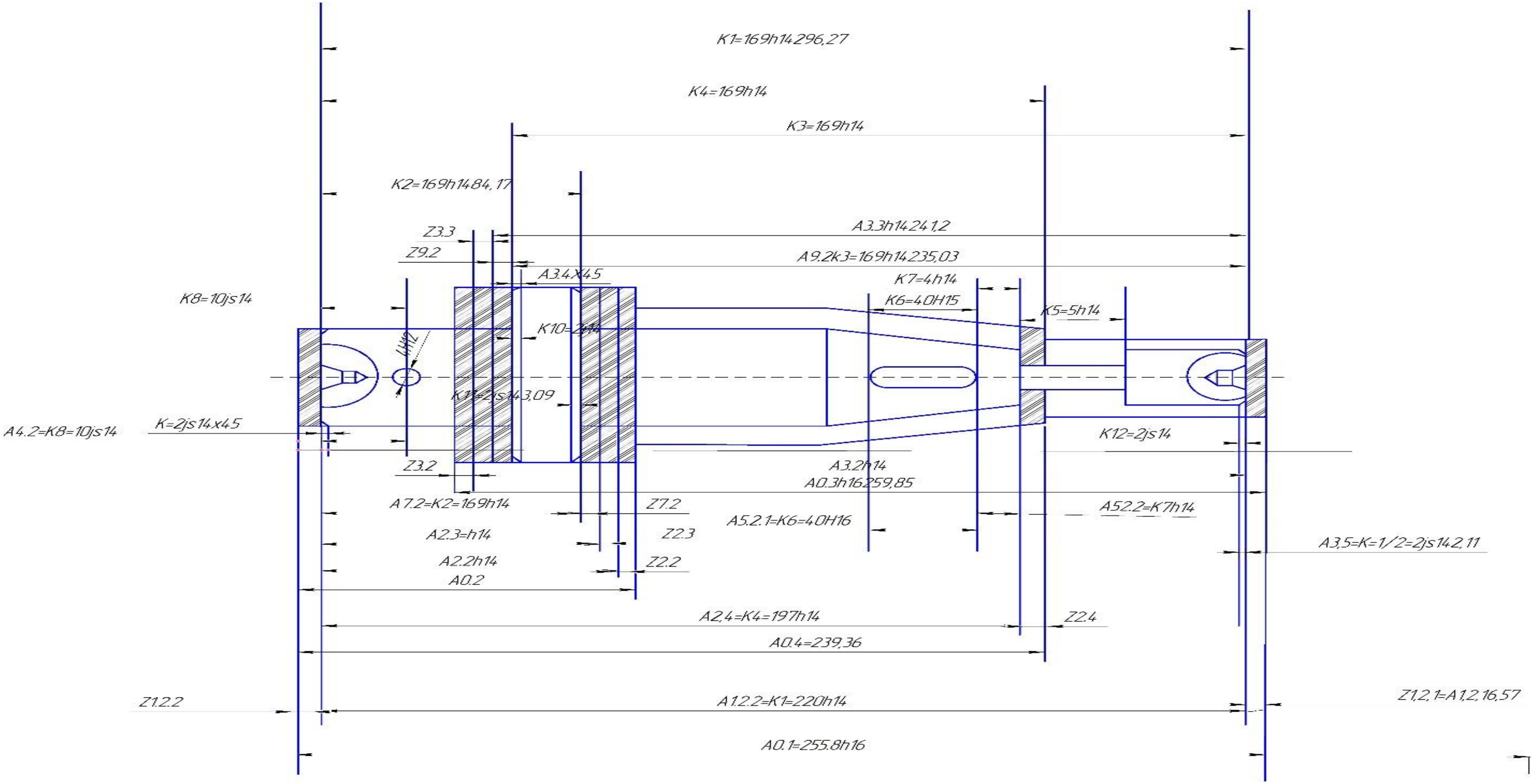


Fig. 5.1. Complex scheme of shaft machining in axial direction

We draw size circuits of a **desirable** design size machining (for example, fig. 5.2). Then we check the possibility of solving: it is necessary that

$$\sum TA_i \leq TA_\Delta. \qquad (5.1)$$

If it is not there we need to reduce sizes tolerances (or tolerance of only one size) of components links. If our size circuit satisfies the equation (5.1), we may find technological sizes (base and deviations.)

5.1. Maintaining of chamfer size $K_3 = 2j_s14$ (±0.25) ×45º

For maintaining (obtaining at processing) size of left chamfer $K_3 = 2j_s14(\pm0.25)\times45^\circ$ in the general scheme (fig. 5.1) we select a size circuit (fig. 5.2), into which this design size K_3 enters, as it is not maintained directly.

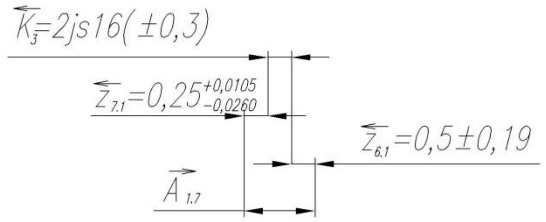


Fig. 5.2. Size circuits for calculation of technological size $A_{1.7}$.

In the size circuit we select the size X_3 which is a part of chamfer, removed after grinding of the hole Ø20H7 (fig. 5.1). As the chamfer is bored under the angle 45º, its size in the axial direction will be equal to the size in radial direction. Changing of chamfer size in a radial direction is defined as a difference of half of diameters between final grinding hole with H7 (technological size $A_{8.2}/2$ = = Ø20H7 $(^{+0.021})/2$) and previous bored hole with H11 (technological size $A_{1.5}/2$= = *Ø19.*5H11 $(^{+0.13})/2$). The tolerances (deviations) thus also are divided half-and-half.

$$X_3 = \frac{D_{8.2}-D_{1.6}}{2} = 10^{+0.01} - 9.75^{+0.026} = 0.25^{+0.01}_{-0.026} \text{ mm.}$$

Before calculating finally the executive technological size (the base size and the deviations are defined) it is necessary to check an opportunity of the solving of a size circuit with the previously accepted technological sizes. It is necessary that the sum of the tolerances of all component parts ($\sum TA_i$) should be less or equal to the tolerance of an initial (closing) link (TA_Δ) (equation (5.1).

In our case:

$K_3 = \sum A_{inc} - \sum A_{red}$;

$K_3 = (A_{7.2} + A_{1.5}) - (X_3 + A_{7.1})$;

TX_3 = 0,036 mm

$TA_{7.2}$ = 0,062 mm

$TA_{1.5}$ =

$TA_{7.1}$ = 0,19 mm

TK_3 = 0,25 mm;

Check to see if the task is solvable:

$TK3 \geq \sum TA_i = TA_{7.2} + TA_{1.5} + TX_3 + TA_{7.1}$ = 0,062 + $TA_{1.5}$ + 0,036 + 0,19 =

$= TA_{1.5} + 0{,}288;$

$TA_{1.5} \leq TK_3 – 0{,}288 = 0{,}25 – 0{,}288 = – 0{,}038$ mm

The task cannot be solved with these tolerances. Reduction of the tolerance of the component links is inexpedient, as the accuracy is high. Let's calculate the sum of the tolerances at new tolerance T K_3 = 0,6 mm:

$\sum T_{Ai} = TA_{7.2} + TA_{1.5} + TX_3 + TA_{7.1} = 0{,}062 + TA_{1.5} + 0{,}036 + 0{,}19 =$

$= TA_{1.5} + 0{,}288 \leq TK_3;$

$TA_{1.5} \leq 0{,}6 – 0{,}288 = 0{,}312$ mm

With this new tolerance, the task is solvable.

After that we write the equation of the size circuit, where in the left part we write the base size of a closing link (in our case K_3) (initial link is the name, as for this closing link it is required to maintain deviations given by the designer), and in the right part from the sum of the base sizes of increasing links the sum of the base sizes of reducing links is subtracted.

Therefore character of all making parts at first is determined. For this purpose one of the component links nearest to the closing link (in our case it can be X_3) is increased in the direction of the closing link. If thus the closing link is increased too, the considered component link is (on character) increasing. If the closing link on the contrary is decreased, the considered component link is reducing. Above a designation of a considered component link the pointer is put down: → (from left to right) - for increasing link; ← (on the right; on the left) - for reducing. After that we bypass the contour of the size circuit, putting down a pointer in the direction of bypassing, thus automatically defining character of all component links.

In our case we define at first the character of the link $A_{7.2}$ - it is an increasing link. Link X_3 - is reducing, $A_{1.5}$ - is increasing, $A_{7.1}$ - is reducing.

We write the equation of the size circuit:

$K_3 = (A_{7.2} + A_{1.5}) – (X_3 + A_{7.1}).$

We substitute numerical values of links:

$2 = (50 + A_{1.5}) – (0{,}25 + 50{,}5);$

We calculate the **base size** of the link $\mathbf{A_{1.5}}$:

$A_{1.5} = 2 – 50 + 50{,}5 + 0.25 = 2{,}75$ mm.

We accept the base value of the link $A_{1.5}$: = 2,75 mm.

We write the equation of a size circuit for the **upper deviation** Δ^u_{K3} of the closing link K_3:

$\Delta^u_{K3} = (\Delta^u_{A7.2} + \Delta^u_{A1.5}) – (\Delta^l_{X3} – \Delta^l_{A7.1});$

We substitute numerical values of links deviations:

$+0.3 = (0 + \Delta^u_{A1.5}) – [(-0{,}026) + (-0.19)];$

We calculate the upper deviation of the link $A_{1.5}$:

$\Delta^u_{A1.5} = 0.3 – 0.19 – 0.026 = +0.084$ mm.

We accept the **upper deviation** of the link $\mathbf{A_{1.5}}$: = +0.084 mm.

We write the equation of the size circuit for the **lower deviation** Δ^u_{K3} of the closing link, substitute numerical values of links deviations and calculate the lower deviation of the link $A_{1.5}$:

$\Delta^l_{K3} = (\Delta^l_{A7.2} + \Delta^l_{A1.5}) – (\Delta^u_{X3} + \Delta^u_{A7.1});$

$-0.3 = [(-0.062) + \Delta^{l}_{A1.5}] – [(+0.01) + 0]$;
$\Delta^{l}_{A1.5} = -0.3 + 0.062 + 0.01 = -0.228$ mm.
We accept the **lower deviation** of the link $\mathbf{A_{1.5}}$: = -0.228 mm.
Hence, the technological size $A_{1.5}$ is necessary to maintain at boring of right chamfer in second operation: $A_{1.5} = 2.75^{+0.084}_{-0.228}$ mm.
We calculate the **tolerance** of the size $A_{1.5}$:
$T_{A1.5} = \Delta^{u}_{A1.5} - \Delta^{l}_{A1.5} = +0.084 – (-0.228) = 0.312$ mm.
We compare $TA_{1.5}$ with the previously determined tolerance ($TA_{1.5}$).

5.2. Maintaining of chamfer size K_4 =3j$_s$14 (±0.25) ×45º

For maintaining size of right chamfer K_4 =3j$_s$16(±0.25)×45º in the general scheme (fig. 5.1) we select a size circuit (fig. 5.3), into which this design size K_4 enters, as it is not maintained directly.
In the size circuit we do as in previous case: we select the size X_4 which is the part of chamfer, removed after grinding of the hole Ø20H7 (fig. 5.1). As the chamfer is bored under the angle 45º, its size in the axial direction will be equal to the size in radial direction. Changing of chamfer size in a radial direction is defined as a difference of half of diameters between final grinding hole with H7 (technological size $A_{8.2}/2$ = = *Ø20H7 ($^{+0.021}$) /2*) and previous bored hole with H11 (technological size $A_{1.5}/2$= = *Ø19.5H11 ($^{+0.13}$) /2*). The tolerances (deviations) thus also are divided half-and-half.

$X4 = \frac{D_{8.2}-D_{1.6}}{2} = 10^{+0.01} – 9.75^{+0.026} = 0.25^{+0.01}_{-0.026}$mm.

Before we calculate finally the executive technological size (the base size and the deviations are defined) it is necessary to check an opportunity of the solution of a size circuit with the previously accepted technological sizes. It is necessary that the sum of the tolerances of all component parts ($\sum TA_i$) should be less or equal to the tolerance of an initial (closing) link (TA_Δ) (equation (5.1).
In our case:
$K_4 = \sum A_{inc} – \sum A_{red}$;
$K_4 = (A_{7.2} + A_{1.7}) – (X_4 + A_{7.1})$;
TX_4 = 0,036 mm
$TA_{7.2}$ = 0,062 mm
$TA_{1.7}$ =
$TA_{7.1}$ = 0,19 mm
TK_4 = 0,25 mm;
Check to see if the task is solvable:
$TK_4 \geq \sum TA_i = TA_{7.2} + TA_{1.7} + TX_4 + TA_{7.1} = 0,062 + TA_{1.7} + 0,036 + 0,19 =$
$= TA_{1.7} + 0,288$;
$TA_{1.7} \leq TK_4 – 0,288 = 0,25 – 0,288 = – 0,038$ mm
The task cannot be solved with these tolerances. Reduction of the tolerance of the component links is inexpedient, as the accuracy is high. Let's calculate the sum of the tolerances at new tolerance T K_4 = 0,6 mm:
$\sum T_{Ai} = TA_{7.2} + TA_{1.7} + TX_4 + TA_{7.1} = 0,062 + TA_{1.7} + 0,036 + 0,19 =$

$= TA_{1.7} + 0{,}288 \leq TK_4$;
$TA_{1.7} \leq 0{,}6 – 0{,}288 = 0{,}312$ mm
With this new tolerance, the task is solvable.
After that we write the equation of the size circuit, where in the left part we write the base size of a closing link (in our case K_4) (initial link is the name, as for this closing link it is required to maintain deviations given by the designer), and in the right part from the sum of the base sizes of increasing links the sum of the base sizes of reducing links is subtracted.
Therefore character of all making parts at first is determined. For this purpose one of the component links nearest to the closing link (in our case it can be X_4) is increased in the direction of the closing link. If thus the closing link is increased too, the considered component link is (on character) increasing. If the closing link on the contrary is decreased, the considered component link is reducing. Above a designation of a considered component link the pointer is put down: → (from left to right) - for increasing link; ← (on the right; on the left) - for reducing. After that we bypass the contour of the size circuit, putting down a pointer in the direction of bypassing, thus automatically defining character of all component links.
In our case we define at first the character of the link $A_{7.2}$ - it is an increasing link. Link *X4* - is reducing, $A_{1.7}$ - is increasing, $A_{7.1}$ - is reducing. We write the equation of the size circuit:
$K_4 = (A_{7.2} + A_{1.7}) – (X_4 + A_{7.1})$.
We substitute numerical values of links:
$3 = (50 + A_{1.7}) – (0{,}25 + 50{,}5)$;
We calculate the **base size** of the link $\mathbf{A_{1.7}}$:
$A_{1.7} = 3 – 50 + 50{,}5 + 0.25 = 3{,}75$ mm.
We accept the base value of the link $A_{1.7}$: = 3,75 mm.
We write the equation of a size circuit for the **upper deviation** Δ^u_{K4} of the closing link K_4:
$\Delta^u_{K4} = (\Delta^u_{A7.2} + \Delta^u_{A1.7}) – (\Delta^l_{X4} – \Delta^l_{A7.1})$;
We substitute numerical values of links deviations:
$+0.3 = (0 + \Delta^u_{A1.7}) – [(-0{,}026) + (-0.19)]$;
We calculate the upper deviation of the link $A_{1.7}$:
$\Delta^u_{A1.7} = 0.3 – 0.19 – 0.026 = +0.084$ mm.
We accept the **upper deviation** of the link $\mathbf{A_{1.7}}$: = +0.084 mm.
We write the equation of the size circuit for the **lower deviation** Δ^u_{K4} of the closing link, substitute numerical values of links deviations and calculate the lower deviation of the link $A_{1.7}$:
$\Delta^l_{K4} = (\Delta^l_{A7.2} + \Delta^l_{A1.7}) – (\Delta^u_{X4} + \Delta^u_{A7.1})$;
$-0.3 = [(-0.062) + \Delta^l_{A1.7}] – [(+0.01) + 0]$;
$\Delta^l_{A1.7} = -0.3 + 0.062 + 0.01 = -0.228$ mm.

We accept the **lower deviation** of the link $\mathbf{A_{1.7}}$: = -0.228 mm.
Hence, the technological size $A_{1.7}$ is necessary to maintain at boring of right chamfer in second operation: $A_{1.7} = 3.75^{+0.084}_{-0.228}$ mm.

We calculate the **tolerance** of the size $A_{1.7}$:
$T_{A1.7} = \Delta^{u}_{A1.7} - \Delta^{l}_{A1.7}$ = +0.084 – (-0.228) = 0.312 mm.
We compare $TA_{1.7}$ with the previously determined tolerance ($TA_{1.7}$).

5.3. Maintaining size $К_2$ =20j_s14 (±0.26)
For maintaining size $К_2$ =20j_s16(±0.26) in the general scheme (fig. 5.1) we select a size circuit (fig. 5.4), into which this design size $К_2$ enters, as it is not maintained directly.
In the size circuit we have to obtain the right size for technological process $A_{3.2}$ to be able to maintain size K_2.
Before we calculate finally the executive technological size (the base size and the deviations are defined) it is necessary to check an opportunity of the solution of a size circuit with the previously accepted technological sizes. It is necessary that the sum of the tolerances of all component parts ($\sum TA_i$) should be less or equal to the tolerance of an initial (closing) link (TA_Δ) (equation (5.1).
In our case:
$K_2 = \sum A_{inc} - \sum A_{red}$;
$K_2 = (A_{3.2} + A_{7.1}) - A_{2.2}$;
$TA_{3.2}$ =
$TA_{7.1}$ = 0,19 mm
$TA_{2.2}$ = 0.19 mm
TK_2 = 0,26 mm;
Check to see if the task is solvable:
$TK_2 \geq \sum TA_i = TA_{3.2} + TA_{7.1} + TA_{2.2} = TA_{3.2}$ + 0,19 + 0,19 =
= $TA_{3.2}$ + 0,38;
$TA_{3.2} \leq TK_2$ – 0,38 = 0,26 – 0,38 = 0,14 mm
With this tolerance the task is solvable.
After that we write the equation of the size circuit, where in the left part we write the base size of a closing link (in our case K_2) (initial link is the name, as for this closing link it is required to maintain deviations given by the designer), and in the right part from the sum of the base sizes of increasing links the sum of the base sizes of reducing links is subtracted.
Therefore character of all making parts at first is determined. For this purpose one of the component links nearest to the closing link (in our case it can be $A_{7.1}$) is increased in the direction of the closing link. If thus the closing link is increased too, the considered component link is (on character) increasing. If the closing link on the contrary is decreased, the considered component link is reducing. Above a designation of a considered component link the pointer is put down: → (from left to right) - for increasing link; ← (on the right; on the left) - for reducing. After that we bypass the contour of the size circuit, putting down a pointer in the direction of bypassing, thus automatically defining character of all component links.
In our case we define at first the character of the link $A_{3.2}$ - it is an increasing link. Link $A_{2.2}$ - is reducing, we write the equation of the size circuit:
$K_2 = (A_{3.2} + A_{7.1}) - A_{2.2}$

We substitute numerical values of links:
$20 = (A_{3.2} + 50.5) – 51$;
We calculate the **base size** of the link $\mathbf{A_{3.2}}$:
$A_{3.2} = 20 – 50,5 + 51 = 20,5$ mm.
We accept the base value of the link $A_{3.2}$: = 20,5 mm.
We write the equation of a size circuit for the **upper deviation** Δ^u_{K2} of the closing link K_2:
$\Delta^u_{K2} = (\Delta^u_{A3.2} + \Delta^u_{A7.1}) – \Delta^l_{A2.2}$;
We substitute numerical values of links deviations:
$+0.26 = (\Delta^u_{A3.2} + 0) – (-0.19)$;
We calculate the upper deviation of the link $A_{3.2}$:
$\Delta^u_{A3.2} = 0.26 – 0.19 = +0.07$ mm.
We accept the **upper deviation** of the link $\mathbf{A_{3.2}}$: = +0.07 mm .
We write the equation of the size circuit for the **lower deviation** Δ^u_{K2} of the closing link, substitute numerical values of links deviations and calculate the lower deviation of the link $A_{3.2}$:
$\Delta^l_{K2} = (\Delta^l_{A3.2} + \Delta^l_{A7.1}) – \Delta^u_{A2.2}$;
$-0.26 = [\Delta^l_{A3.2} + (-0,19)] – 0$;
$\Delta^l_{A3.2} = -0.26 + 0.19 = -0.07$ mm.
We accept the **lower deviation** of the link $\mathbf{A_{3.2}}$: = -0.07 mm.
Hence, the technological size $A_{3.2}$ is necessary to maintain at drilling of hole $5H12^{(+0.12)}$) in third operation: $A_{3.2} = 20.5^{+0.07}_{-0.07}$ mm.
We calculate the **tolerance** of the size $A_{3.2}$:
$T_{A3.2} = \Delta^u_{A3.2} - \Delta^l_{A3.2} = +0.07 – (-0.07) = 0.14$ mm.

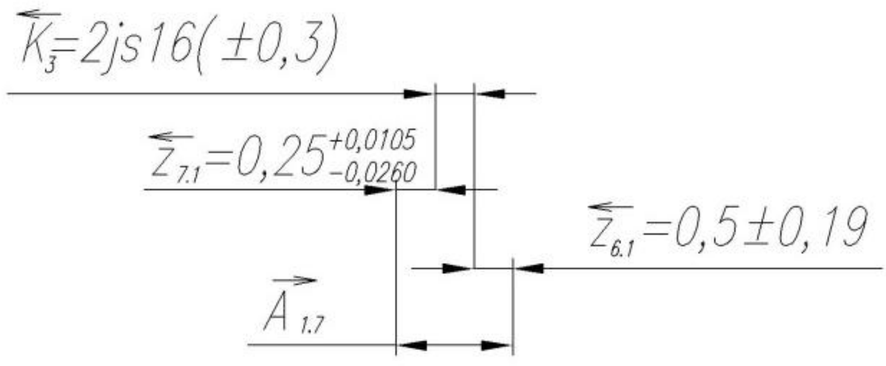


Fig. 5.3. Size circuit for calculation dimension $A_{1.7}$.

5.4. Maintaining size $K_5 = 5h14^{(-0.3)}$

For maintaining size K5 $=5h14^{(-0.3)}$ in the general scheme (fig. 5.1) we select a size circuit (fig. 5.5), into which this design size K_5 enters, as it is not maintained directly.
In the size circuit we have to obtain the right size for technological process $A_{4.2.1}$ to be able to maintain size K_5.

Before we calculate finally the executive technological size (the base size and the deviations are defined) it is necessary to check an opportunity of the solution of a size circuit with the previously accepted technological sizes. It is necessary that the sum of the tolerances of all component parts ($\sum TA_i$) should be less or equal to the tolerance of an initial (closing) link (TA_Δ) (equation (5.1).

In our case:

$K_5 = \sum A_{inc} - \sum A_{red}$;

$K_5 = (A_{7.2} + A_{4.2.1}) - A_{7.1}$;

$TA_{7.2} = 0.062$ mm

$TA_{4.2.1} =$

$TA_{7.1} = 0.19$ mm

$TK_5 = 0{,}3$ mm;

Check to see if the task is solvable:

$TK_5 \geq \sum TA_i = TA_{7.2} + TA_{7.1} + TA_{4.2.1} = 0{,}062 + TA_{4.2.1} + 0{,}19 =$

$= TA_{4.2.1} + 0{,}252$;

$TA_{4.2.1} \leq TK_5 - 0{,}252 = 0{,}3 - 0{,}252 = 0{,}048$ mm

With this tolerance the task is solvable.

After that we write the equation of the size circuit, where in the left part we write the base size of a closing link (in our case K_5) (initial link is the name, as for this closing link it is required to maintain deviations given by the designer), and in the right part from the sum of the base sizes of increasing links the sum of the base sizes of reducing links is subtracted.

Therefore character of all making parts at first is determined. For this purpose one of the component links nearest to the closing link (in our case it can be $A_{7.2}$) is increased in the direction of the closing link. If thus the closing link is increased too, the considered component link is (on character) increasing. If the closing link on the contrary is decreased, the considered component link is reducing. Above a designation of a considered component link the pointer is put down: → (from left to right) - for increasing link; ← (on the right; on the left) - for reducing. After that we bypass the contour of the size circuit, putting down a pointer in the direction of bypassing, thus automatically defining character of all component links.

In our case we define at first the character of the link $A_{4.2.1}$ - it is an increasing link. Link $A_{7.1}$ - is reducing, we write the equation of the size circuit:

$K_5 = (A_{7.2} + A_{4.2.1}) - A_{7.1}$

We substitute numerical values of links:

$5 = (50 + A_{4.2.1}) - 50.5$;

We calculate the **base size** of the link $\mathbf{A_{4.2.1}}$:

$A_{4.2.1} = 5 - 50{,}5 + 50 = 5{,}5$ mm.

We accept the base value of the link $A_{3.2}$: = 5,5 mm.

We write the equation of a size circuit for the **upper deviation** Δ^u_{K5} of the closing link K_5:

$\Delta^u_{K5} = (\Delta^u_{A7.2} + \Delta^u_{A4.2.1}) - \Delta^l_{A7.1}$;

We substitute numerical values of links deviations:

$0 = (0 + \Delta^u_{A3.2}) - (-0.19)$;

We calculate the upper deviation of the link $A_{4.2.1}$:
$\Delta^u_{A4.2.1} = 0 – 0.19 = -0.19$ mm.
We accept the **upper deviation** of the link $\mathbf{A_{4.2.1}}$: = -0.19 mm.
We write the equation of the size circuit for the **lower deviation** Δ^u_{K5} of the closing link, substitute numerical values of links deviations and calculate the lower deviation of the link $A_{4.2.1}$:
$\Delta^l_{K5} = (\Delta^l_{A7.2} + \Delta^l_{A4.2.1}) – \Delta^u_{A7.1}$;
$-0.48 = [(-0,062) + \Delta^l_{A4.2.1}] – 0$;
$\Delta^l_{A4.2.1} = -0.48 + 0.062 = -0.418$ mm.
We accept the **lower deviation** of the link $\mathbf{A_{4.2.1}}$: = -0.418 mm.
Hence, the technological size $A_{4.2.1}$ is necessary to maintain at milling of key slot 15H15(+0.7) in fourth operation: $A_{4.2.1} = 5.5^{-0.19}_{-0.42}$ mm.
We calculate the **tolerance** of the size $A_{4.2.1}$:
$T_{A4.2.1} = \Delta^u_{A4.2.1} - \Delta^l_{A4.2.1} = -0.19 – (-0.418) = 0.228$ mm.

6. CALCULATION of CUTTING MODES

Elements of cutting modes are nominated taking into account character of processing, type and sizes of the cutting tool, material of its cutting part, material and surface condition of a blank, type and condition of the equipment.

6.1. Calculation of cutting speed for turning of surface Ø30.9h11

Let's calculate modes of cutting at draft turning of an outside surface of the cartridge ***Ø30.9h11*** in the second operation. The size of the processed surface d_i = ***= Ø30.9h11***. The size of a processable surface - d_{i-1} = ***Ø34h16*** (diameter of forged blank). ***Previously*** we calculate the greatest depth of cutting t_{max}, if we remove all stock on rough (draft) processing for one pass (after 1 stroke):

$$t_{max} = (d_{(i-1)\ max} - d_{i\ min})/2 = = (34 - 30.74)/2 = 1.63 \text{ mm.}$$

The greatest depth of cutting is less than 4 mm [1, page 265], and it is possible to remove all stock for one pass. We ***accept the greatest depth of cutting t_{max} = = 1.63*** mm. Other elements of a mode of cutting are usually established and calculated in the order which has been mentioned below.
Feed rate S is nominated by using machinist handbook [1, p. 266, tab. 11, p. 268, tab. 13 & 14]. At draft processing, choosing feed rate, it is necessary to check up durability of a cutter shank and carbide cutting plate, rigidity of a processable detail and durability of the feed rate mechanism of the machine tool. Feed rate S is usually limited by nose radius R and roughness of processed surface Ra [1, p. 268, tab. 14].
We choose a cutter under the recommendations. A cutter - through passage direct with a cutting plate from cemented carbide T15K6: 2100-01 17-T15K6.
The sizes of the cutter shank are 16×25 mm, diameter 30.9 mm , s_a =0.4-0.5 mm/r [1, p. 266, tab. 11].
On the strength of throwaway-insert tool bit with thickness 4 mm , ultimate tensile stress σ_{uts} of processed part material 40X is 1000 Mpa feed rate s_b is caalculated as: s_b =1.3×0.85×1=1.105 mm/r [1, p. 266, tab. 11].
On durability shank the large feed rate will sustain at rather small depth of cut t=1.63 mm. Therefore finally we choose feed rate proceeding from a required roughness of a surface for draft processing (Ra≤10 microns) and nose radius R =0.80 mm (at draft processing nose radius can be taken large, since the high accuracy is not required and elastic deformation of a cutter and a detail at the greater force P_y does not play main role as at finish processing). Ultimate tensile stress σ_{uts} of processed part material 40X is 1000 Mpa feed rate s_b is caalculated as: s_c =0.8×1.25 =1.0 mm/r [1, p. 268, tab. 14].
We determine feed rate S as minimal from s_a, s_b and s_c: s_a =0.4-0.5 mm/r ≈ s_a =0.43 mm/r – is accepted feed rate.

It is possible to define cutting speed V, mpm, by several methods:

1) calculation by the formula;
2) using table data with the use of correction factors;
3) on the basis of the empirical data (used on the enterprise for the appropriate processable and cutting materials, geometry of the tool etc.)

Let's take advantage of calculation by the formula. For outside longitudinal and cross turning and boring the cutting speed V, mpm (meter per minute), is calculated by the formula:

$$V = \frac{C_V}{(T^m \cdot t^x \cdot s^y)} \cdot K_V , \qquad (6.1)$$

where: T - cutting tool life (period of work of the cutting tool before the wear). At draft processing in small-scale manufacture it is usually T=60 min.
The value of factor C_V and parameters of a degree are given in tab. 17 [1, page 269, table 17]. For considered draft turning of an outside surface we accept that the depth of cut will be equal to the greatest depth of cut: $t = t_{max} = 1.63$ mm.
Factors and parameters of degrees are defined from tab. 17 [1]:

$$C_V=350;\ x=0.15;\ y=0.35;\ m=0.20.$$

K_V - correction factor which takes into account geometry of cutting tool.

$$K_V = K_{Mv} \times K_{Иv} \times K_{Пv} \times K_{\varphi v} \times K_{\varphi 1v} \times K_{Rv} \times K_{Qv} \times K_{Ov} , \qquad (6.2)$$

where $K_{Mv} = K_g \times (750/\sigma_{uts})^{nv}$- is the factor which is take into account influence of quality of a processable material (durability) on cutting speed [1, page 261, table 1]. For steel 40X tensile strength (strength of stretching) $\sigma_{uts}=1000$ MPa, for cemented carbide $K_g = 0.95$, $n_v = 1$ [1, page 262, table 2], therefore:
$K_{Mv} = K_g \times (750/\sigma_{uts})^{nv} = 0.95 \times (750/1000)^1 = 0.71$;
$K_{Иv}$ - factor taking into account material of a cutting part. For a cutting plate from a cemented carbide T15K6 $K_{Иv} = 1$ [1, page 263, table 6];
$K_{Пv} = 0.9$ - factor taking into account a condition of a surface of blank (hot rolled rod) [1, page 263, table 5];
$K_{\varphi v} = 0.7$ - factor taking into account geometrical parameters of a cutter (the main angle in the plan $\varphi=90^o$) [1, page 271, table 18];
$K_{\varphi 1v} = 1$ - factor taking into account geometrical parameters of a cutter (an auxiliary angle in the plan $\varphi_1=10^o$);
$K_{Rv} = 1$ - factor taking into account geometrical parameters of a cutter (nose radius R=2 mm of a cutter), for **cmented carbide** $K_{Rv} = 1$;

$$K_V = 0.71 \times 1 \times 0.9 \times 0,7 \times 1 \times 1 = 0,447 \approx 0.45.$$

$$V = \frac{C_V}{(T^m \cdot t^x \cdot s^y)} \cdot K_V = \frac{350}{(60^{0.2} \cdot 1.63^{0.15} \cdot 0.43^{0.35})} \cdot 0.45 = 128 \text{ mpm.}$$

We calculate number of revolutions of a spindle per 1 minute (frequency of spindle rotation) n_{cal}:

$$n_{cal} = \frac{1000 \cdot V}{\pi \cdot d_{max}} = \frac{1000 \cdot 128}{\pi \cdot 30.9} = 1319 \text{ r/min}$$

where: d_{max} - diameter of machined surface, mm.

In the technical passport of the machine tool we find the nearest smaller number of revolutions of a spindle (smaller - since even at insignificant increasing of cutting speed can result an essential reduction of cutting tool life *T*): n_{pas} = 1250 rev/min. We calculate the ***real*** (specified or corrected) ***cutting speed*** at the accepted number of revolutions of a spindle:

$$V = \frac{\pi \cdot d \cdot n_{pas}}{1000}, \text{ mpm.} \qquad (6.6)$$

In our case the real speed of cutting Nr:

$$V_{\partial} = \frac{\pi \cdot 30.9 \cdot 1250}{1000} = 121 \text{ mpm.}$$

We accept n_{acc}= 1250 r/min.

It is accepted to split the force of cutting P on making (component) forces which are directed on axes of coordinates of the machine tool (Pz, Py, Px) to make calculations easer.
For outside longitudinal turning [1, page 271]:

$$P_{z,y,x} = C_P \times t^x \times s^y \times V^n \times K_P, \ [\text{N}], \qquad (6.3)$$

where C_P - factor depending on a processable and cutting material; K_P - correction factor.

$$K_P = K_{Mp} \times K_{\varphi p} \times K_{\gamma p} \times K_{\lambda p} \times K_{Rp}, \qquad (6.4)$$

where K_{Mp} - factor taking into account influence of quality of a processable material (durability) on force of cutting. For steel 40X strength on a stretching is σ_{UTS}=1000MPa, therefore $K_{Mp} = (\sigma_{uts} / 750)^{np} = (1000 / 750)^{0.75} = 1.24$
[1, page 264, table 9];

$K_{\varphi p}$ - factor taking into account influence of the main angle in the plan φ on a force of cutting, $K_{\varphi p}$ =0.89 [1, page 275, table 23];
$K_{\gamma p}$- factor taking into account influence of the main forward angle in main crossection plane γ (rake angle) on force of cutting, $\gamma=7^\circ$; $K_{\gamma p}$ =1.0 [1, page 275, table 23];
$K_{\lambda p}$ - factor taking into account influence of an inclination main cutting edge angle λ on force of cutting, $\lambda=0^\circ$; $K_{\lambda p}$ =1;
K_{Rp} - factor taking into account influence of cutter nose radius R on force of cutting, R=2 mm, K_{Rp} =1;

For considered draft turning of an outside surface ***Ø30.9h11*** in the second operation we accept that depth of cut t will be equal to the greatest depth of cut t_{max}: $t = t_{max}$ = 1.63 mm. Factors and parameters of degrees found in tab. 22 [1, page 273, table 22] we write in tab. 6.1.

Table 6.1. Calculation of cutting component forces at rough turning ***Ø30.8h11***

Compo-nents	C_P	x	y	n	K_{Mp}	$K_{\varphi p}$	$K_{\gamma p}$	$K_{\lambda p}$	K_{Rp}	K_P	$P_{z,y,x}$, N
P_z	300	1	0.75	-0.15	1.24	0.89	1	1	1	1.1	1425.4

$P_z = 10 \times 300 \times 1.63^1 \times 0.43^{0.75} \times 121^{-0.15} \times 1.1 = 1425.4$ N;

The ***cutting power*** is calculated by the formula:

$$N = \frac{P_z \cdot V}{1020 \cdot 60}, \text{ [kW]} \qquad (6.5)$$

where P_z - tangential component of cutting force (conterminous on a direction with a vector of cutting speed), N; V - cutting speed, mpm.

In our case at rough turning of an outside surface ***Ø30.8h11***:

$$N_{cutting} = \frac{1425.4 \cdot 121}{1020 \cdot 60} = 2.98 \text{ kW.}$$

Power of machine tool (equipment) is calculated:
$N_m = k \times N_{cutting} = (1.5 – 2.5) \times 2.98 = 2 \times 2.98 = 5.96$ kW

6.2. Calculation of cutting modes, forces and power in drilling Ø4H12

We choose the cutting tool by recommendations: a drill Ø4 mm GOST 10902-64; a material of a cutting part - high speed steel (HSS) P6M5, point angle $2\varphi = 118^o$.

Depth of cut at drilling t = 0.5·D = 0.5·4 = 2 mm.

6.2.1. Calculation of cutting modes and forces in drilling Ø4H14 by the calculation method

Maximal feed rate is choused in accordance with rigidness of drill (diameter of drill Ø4 mm), cutting tool material (HSS P6M5), machined material (steel 40X) with hardness HB 200-220 , surface roughness (Ra<10 µm) and recommendations which are given in tab. 27 [1, page 277, table 25]: S = 0.06-0.07 mmpr.

The **cutting speed** at drilling is calculated by the formula:

$$V = \frac{C_V \cdot D^q}{(T^m \cdot s^y)} \cdot K_V \quad , \qquad (6.6)$$

where: T - cutting tool life (at drilling T=45 minutes [1, page 415]).

For **redrilling** or **core-drilling**:

$$V = \frac{C_V \cdot D^q}{(T^m \cdot t^x \cdot s^y)} \cdot K_V \qquad (6.7)$$

Cutting tool life T of drill 4 mm is 15 minutes [1, page 279, table 30]

Values of factor C_V and parameters of a degree for a drill from HSS and drilling in processable constructional steel (steel 40X) are given in tab. 8 [1, page 278, table 28]: $C_V=7.0;\ q_v = 0.4;\quad y=0.7;\ m=0.20.$

K_V - correction factor:

$$K_V = K_{Mv} \times K_{Иv\ \ lv}, \qquad (6.8)$$

where $K_{Mv} = K_g \times (750/\sigma_{uts})^{nv}$- is the factor which is taken into account on the influence of quality of a machined material (durability) on cutting speed [1, page 261, table 1]. For steel 40X tensile strength (strength of stretching) $\sigma_{uts}=1000$ MPa, for high speed steel K_g = 0.85, n_v =0.9 [1, page 262, table 2], therefore:

$K_{Mv} = K_g \times (750/\sigma_{uts})^{nv} = 0.85 \times (750/1000)^{0.9} = 0.65$;

$K_{Иv}$ - factor which taking into account material of a cutting part. For a drill from HSS P6M5 $K_{Иv}$ =0.3 [1, page 436];

K_{lv} =0.4 - factor which is taken into account depth of a drilled hole (L<8D) (L =30, D = 4 mm, L/D = 30/4 = 8) [1, page 280, table 31] .

$$K_V = 0.65 \times 0.4 \times 1 = 0.26.$$

$$V = \frac{C_V \cdot D^q}{(T^m \cdot s^y)} \cdot K_V = \frac{7 \cdot 4^{0.4}}{(15^{0.2} \cdot 0.06^{0.5})} \cdot 0.26 = 12.2 \text{ m/m.}$$

The **torsion moment** in drilling is calculated by the formula [1, p.277] :

$$M_c = 10 \cdot C_M \cdot D^q \cdot S^y \cdot K_p , \ [N \cdot m] \quad (6.9)$$

where: C_M·=0.0345 - factor which is taking into account machinability of a material (in our case it is unquenched steel 40X) [1, p.281, table 32]; $q = 2; y = 0,8; K_p = K_m = (\sigma_{uts}/750)^n$. [1, p.264, table 9];
$K_p = (\sigma_{uts}/750)^n = (1000/750)^{0.75} = 1.23$

$$M = 10 \cdot 0.0345 \cdot 4^2 \cdot 0.06^{0.8} \cdot 1.23 = 0.71 \ N \cdot m.$$

The **axial force** in drilling is calculated by the formula [1, p.277] :

$$P_{ax} = 10 \cdot C_P \cdot D^q \cdot S^y \cdot K_p , \ [N] \quad (6.10)$$

where: C_P = 68 - factor which is taking into account durability of a processable material (in our case - unquenched steel 40X) [1, p.281, table 32]; $q_p = 1; y_P = 0,7;$ $K_p = K_m = (\sigma_{uts}/750)^n$. [1, p.264, table 9];
$K_p = (\sigma_{uts}/750)^n = (1000/750)^{0.75} = 1.23$.

$$P_{ax} = 68 \cdot 4^1 \cdot 0.43^{0,7} \cdot 1.23 = 185.3 \ N.$$

For calculation of cutting power it is necessary to know **frequency of a spindle rotation n**. We calculate number of revolutions of a spindle n_{cal}:

$$n_{cal} = \frac{1000 \cdot V}{\pi \cdot d_{\max}} = \frac{1000 \cdot 12.2}{\pi \cdot 4} = 970.9 \text{ rpm},$$

where d_{max} – the greatest diameter of working cutting edge relatively of axis of the rotating tool, mm.

In the technical passport of the machine tool we find the nearest smaller number of revolutions of a spindle (smaller - since even at insignificant increasing of cutting speed can result an essential reduction of cutting tool life *T*): n_{pas} = = 1000 rpm. We calculate the ***real*** (specified or corrected) ***cutting speed*** at the accepted number of revolutions of a spindle by the formula (6.6):

$$V_r = \frac{\pi \cdot d \cdot n_{pas}}{1000} = \frac{3.14 \cdot 4 \cdot 1000}{1000} = 12.6 \text{ mpm.}$$

Cutting power at drilling Ø4H14 is calculated by the formula:

$$N = \frac{M \cdot n}{9750} = \frac{0.71 \cdot 1000}{9750} = 0.073 \text{ kW} \qquad (6.11)$$

6.2.2. Calculation of cutting modes and forces in drilling Ø4H14 by the table method

We choose the tool under the recommendations [2, page 450]: a drill Ø5 mm GOST 10902-64; a material of a cutting part - HSS P6M5, point angle 2φ = 118º.

Depth of cut at drilling t = 0.5·D = 0.5·5 = 2.5 mm. Using a tabulared method, we determine cutting modes. Maximal feed rate is determined by the recommendations [3, page 253]: group of feed rate -1, S_r = = 0.1 mmpr.

Cutting speed at drilling is determined by the recommendations [3, page 245]:

$$V = V_{tab} \cdot K_1 \cdot K_2\ K_3, \qquad (6.12)$$

where K_1=1.3; K_2=1.15; K_3=1. V_{tab}= 24 mpm [3, page 245]. Then:

$$V = V_{tab} \cdot K_1 \cdot K_2\ K_3 = 24 \cdot 1.3 \cdot 1.15 \cdot 1 = 35.88 \text{ mpm.}$$

We calculate number of revolutions of a spindle n_{cal}:

$$n_{cal} = \frac{1000 \cdot V}{\pi \cdot d_{\max}} = \frac{1000 \cdot 35.88}{\pi \cdot 5} = 2285 \text{ rpm.}$$

In the technical passport of the machine tool we find the nearest smaller number of a spindle revolutions: n_{pas} = 2000 rpm. We correct the real cutting speed at the accepted number of revolutions of a spindle by the formula (6.6):

$$V_r = \frac{\pi \cdot d \cdot n_{pas}}{1000} = \frac{3.14 \cdot 5 \cdot 2000}{1000} = 31.4 \text{ mpm.}$$

We calculate axial force of cutting:

$$P_{ax} = P_{tab} \cdot K_p = 110 \cdot 0.75 = 82.5 \text{ kg.} = 825 \text{ N} \qquad (6.13)$$

We calculate cutting power:

$$N = N_{tab} \cdot K_p \cdot n = 0.2 \cdot 0.75 \cdot 2000 = 300 \text{ W} = 0.3 \text{ kW.} \qquad (6.14)$$

Required power of the electric motor of the machine tool:

$$N_{mach} > N \cdot 1.12 = 0.3 \cdot 1.12 = 0.336 \text{ kW}.$$

6.3. Calculation of cutting modes and power in saw (disk) milling of face end in first operation

Initial data: diameter of cut off rod is 35 mm for length 56 mm, steel 40X.
Saw milling cutter is made from HSS steel P6M5 [1, table 86, p. 184], diameter 100 mm, execution 3, quantity of teeth is 40, width is 3 mm, hole diameter is 32 mm [GOST 2679-73]. Feed rate per tooth is S_z=0,05 mm/tooth [1, table 33, p. 283]. Cutting speed is calculated by formula

$$V = \frac{C_V \cdot D^q}{(T^m \cdot t^x \cdot s_z^{\ y} \cdot B^u \cdot z^p)} \cdot K_V \quad , \qquad (6.15)$$

where: T – cutting tool life (for saw mills with diameter from 90 to 150 mm T=120 minutes [1, table 40, p. 290].

Coefficient C_V and exponents we determine for HSS saw mills in cutting with cutting fluid in table 39 [1, table. 39, p. 286]:

$C_V=53;\ q = 0.25;\ x=0.3;\ y=0.2;\ u=0{,}2;\ p=0{,}1;\ m=0.2.$

K_V - coefficient for machined material :

$$K_V = K_{Mv} \times K_{sv} \times K_{tv}\ , \qquad (6.16)$$

where $K_{Mv} = K_g \times (750/\sigma_{uts})^{nv}$- is the factor which is taken into account on the influence of quality of a machined material (durability) on cutting speed [1, page 261, table 1]. For steel 40X tensile strength $\sigma_{uts}=1000$ MPa, for high speed steel K_g = 0.85, n_v =0.9 [1, page 262, table 2], therefore:

$K_{Mv} = K_g \times (750/\sigma_{uts})^{nv} = 0.85 \times (750/1000)^{0.9} = 0.65$;

K_{sv} - factor which taking into account quality of workpiece surface [1, page 436]. K_{sv} =1;

K_{tv} - factor which taking into account material of a milling cutter. For a mill, made from HSS P6M5, K_{tv} =1 [1, page 436];

$$K_V = 0.65 \times 1 \times 0{,}9 = 0{,}585.$$

$$V = \frac{C_V \cdot D^q}{(T^m \cdot t^x \cdot s_z^{\ y} \cdot B^u \cdot z^p)} \cdot K_V = \frac{53 \cdot 100^{0.3}}{(120^{0.2} \cdot 35^{0.3} \cdot 0.05^{0.2} \cdot 3^{0{,}2} \cdot 40^{0{,}1})} \cdot 0{,}59 = 16.83 \text{ m/min}.$$

Quantity of mill's revolution n_{calc}:

$$n_{calc} = \frac{1000 \cdot V}{\pi \cdot d} = \frac{1000 \cdot 16.83}{3.14 \cdot 100} = 53{,}6 \text{ r/min},$$

где d – diameter of mill, mm.

Accept n_{mill}= 63 r/min.

6.4. Calculation of cutting modes and power at cylindrical grinding Ø30g6

We choose the cutting tool by recommendations [1, pages 242, 245, 246, 249, 250, 252 - 254]:

1. The **type of abrasive** is 14A (normal aluminum oxide) [1, pages 242] or A (Alundum) in accordance with American terminology. Aluminum oxide grains or crystals, although not the hardest artificial abrasive, are tough and are best for grinding materials of high-tensile strength. They are used to grind carbon steels, alloy steels, soft or hard steels, cast-alloy cutting tools, wrought iron, and tough bronze.
2. The **grain size** - 25 (fine grinding of parts with Ra<0.8 μm and with grade of tolerance 6) [1, page 247]. Grain refers to the size of the abrasive particles used in the manufacture of the grinding wheel. The grain size is determined by the **mesh number** of the finest screen through which the grain will pass. For example, a 36-grain wheel is one made of particles of abrasive which just pass through a 36-mesh screen, but which will be retained on a 46-mesh screen, the next finer screen. (A 36-mesh screen has 36 openings each lineal 25.4 mm, or 200 openings per square centimeter. Grain numbers are sometimes called **grit numbers**.
3. The **bond** material is K2 (S2 in accordance with American terminology) (silicate-bonded wheels which are used for grinding steel parts) [1, page 247]. The **bond** is the material which holds the abrasive grains together to form the grinding wheel. As the grains get dull, pressure on the wheel causes the bond to break down and release the dull grains, thus exposing new sharp grains. The bond holds the individual grain in much the same manner as a tool holder holds a tool bit. There are five basic types of bonds used in grinding wheels: **vitrified, silicate, rubber, shellac, and resinoid**. Additional modifications of these five materials are also produced by some manufacturers. Approximately 75% of all wheels are made with **vitrified** or a modified vitrified bond. Vitrified-bond wheels are strong, porous, and are not affected by rapid changes in temperature, oils, acid, or water. These wheels are uniform in structure, free from hard spots, and hold their form well. The bond is formed when special clays are mixed with abrasive grains and heated to high temperatures. The mixture forms a molten glass which cements the grains together. Wheels bonded with **silicate** (silicate of soda) are known as silicate- or semi-vitrified-bond wheels. Silicate-bonded wheels release the grains more readily than vitrified bond. Hence, the wheel is softer and it breaks down more readily, thereby exposing new sharp grains. Silicate-bonded wheels are used for grinding steel parts, edge tools, drills, reamers, milling cutters, and similar tools.
4. The **hardness of grinding wheel** is CM2 (which is rated between soft and medium) [4, page 59] or H grade in accordance with American terminology. Wheels from which the grit or abrasive is readily torn are

termed **soft grade**. Conversely, wheels that do not readily release the grain are called **hard grade**. **Hard-grade** wheels generally are used **for grinding soft** metals such as mild steel. **Soft-grade** wheels generally are used **for grinding hard** metals such as high-carbon steel. It should be remembered that the term hard as used with respect to grinding wheels has no relationship to the hardness of the abrasive, but rather to the ease or difficulty with which the worn particles of the abrasive are torn from the face of the wheel. With a given bond material, it is the amount of bond which determines the hardness or softness of the wheel - the more bond material, the harder the wheel. The grade of grinding wheels is designated by letters of the alphabet, A being the softest and Z the hardest, [4, table 22-2].

5. The **structure** of a grinding wheel is 6 (middle density). The **structure** of a grinding wheel refers to the spacing between the grains, or the density of the wheel. Grains which are very closely spaced are denser or close, while grains which are wider apart are less dense or open. The structure of a wheel is rated with numbers from 1 (dense) to 15 (open). The rate of metal removal usually is greater for wheels with an open structure. However, those with dense structure usually produce a finer finish.

The marking on the grinding wheel is ЧК 250-25-50 14А 25 СМ2 6 К2/ППС 40 15 in accordance with Russian terminology. This marking indicates that the type of grinding wheel is bowl-plate shape (ЧК), external diameter is 250 mm, height (width) is 25 mm, diameter of hole is 50 mm; type of abrasive is type 14A (normal aluminum oxide); with a 25 medium grain size; with CM2 grade (which is rated between soft and medium); structure 6 (middle density); bond type K2 (which is silicate-bonded); and ППС 40 15 represents the manufacturer's mark for the specific type of silicate bond (the porosity used material is polystyrene ППС with 40 grain size and space containing in abrasive weight is 15 percent. A grinding wheel of this type will do a good job in surface-grinding hardened carbon steel.

The standard system for marking wheels adopted by the American Standards Association includes six parts in sequence, as listed across the top of Table 22-2 [4]. Note that the prefix to item one in the sequence is optional for each manufacturer. For example, where several types of a given abrasive are available, such as several variations of aluminum oxide, the prefix number indicates the exact type of aluminum oxide. Also note that items four and six in the sequence are optional with the manufacturer.

Grinding wheel markings adopted by the American Standards Association is T1 250-25-50 25A -H8SBE [4, page 59]. This marking indicates that the type-number (shape) of grinding wheel is 1 (with straight profile) [1, page 56], the diameter of grinding wheel is 250 mm, the diameter of grinding wheel hole is 50 mm (the diameter of the spindle hole), the height (the width) of grinding wheel is 25 mm, the abrasive is type 25 Alundum with a 25 medium grain size; with H grade (which is rated between soft and medium); structure 8 (middle density); bond type S (which is silicate); and BE represents the manufacturer's mark for the specific type of silicate bond. A grinding wheel of this type will do a good job in surface-grinding hardened carbon steel.

Cutting modes **for feed rate for double pass** are chosen by recommendations [1, pages 301]:

1.Cutting speed V= 30...35 mps (tangential speed of grinding wheel)
n_{gw}= 60000×V/(π×d_{gw}) = 60000×30/(π×250) = 2293 ≈ 2500 rpm.
2. Tangential speed of a part V_p = 20...30 mpm; $n_p = 1000\times V/(\pi\times d_p) =$
$= 1000\times20/(\pi\times30)$ = 212 ≈ 250 rpm; corrected speed of part $V_{p\ cor} = \pi\times d_p\times n_p/1000$ $= = 3.14\times30\times250/1000$ = 23.6 mpm.
3. Depth of cut (of grinding) t = 0.015...0.05 mm. We accept t = 0.03 mm.
4. Lengthwise feed rate S = (0.3...0.7) ×B = 0.5×25 = 12.5 mmpr, where B is the length of working part of the wheel.
5. Quantity of passes is calculated by the formula:

$$i = 2\cdot z_{max\ i}/2\cdot t = z_{max\ i}/t, \qquad (6.17)$$

where $2\cdot z_{max}$ is maximal stock in considered technological transition. Maximal stock is calculated: $2\cdot z_{max\ i}$ = $d_{(i-1)\ max}$ - $d_{i\ min}$ = 30.1 – 29.98 = 0.12 mm.
d_{i-1} =Ø30.1h9($_{-0.062}$), d_i =Ø30g6($_{-0.02}^{-0.007}$).

$$i = 2\cdot z_{max}/2\cdot t = 0.12/2\cdot0.03 = 2.$$

We accept ***i* = 3**, because we are to add one pass for reducing depth of cut in last pass and reducing errors of grinding which are appeared due to elastic recovering of part and machine tool mechanism (errors of size, out of roundness and cylindrical, roughness of surface). We are take into account time for returning grinding well in right side for cross feed of well (idle passes). That is why whole quantity of passes is equal 6 (3 of working and 3 of idle passes).

The **cutting power** for feed rate for double pass at round grinding Ø30h7 is calculated by the formula:

$$N = C_N \times V_p^{\,r} \times t^x \times s^y \times d^q\ , \qquad (6.18)$$

where C_N = 2.65; r = 0.5; x = 0.5; y = 0.55; q = 0 [4, page 301].

$N = C_N \times V_p^{\,r} \times t^x \times s^y \times d^q = 2.65\times 23.6^{0.5} \times 0.03^{0.5} \times 12.5^{0.55} \times 30^0$ = 3.46 kW.

Grinding machine is chosen in accordance with the type of work (grinding of external cylindrical surface), the diameter of processable part (Ø30 mm) and the length (L=51 mm), the required power of grinding driver (N=3.46 kW). We choose plain grinding machine 3M150 [1, page 29] with maximal diameter of processable part Ø100 mm but recommended diameter of external grinding is Ø10…45 mm, maximal length of grinding is 340 mm, maximal longitudinal moving of grinding table with headstock is 400 mm, frequency of blank spindle rotation is stepless (with variable-speed mechanism) from 100 to 1000 rpm, frequency of grinding spindle rotation is 2350 and 1670 rpm for external grinding, maximal diameter of grinding well is 400 mm, maximal height of grinding well is 40 mm, maximal cross moving of grinding tailstock is 80 mm with resolution 0.0005 mm, power of grinding driver is 4 kW, diameter of grinding well hole is 50 mm.

6.6. Calculation of cutting modes and forces at milling key slot 8H9

We choose the cutting tool by recommendations [2, page 450]: **two-flute** single-end milling cutter Ø8 mm from solid cutter made of one piece of high-speed steel P6M5. Two-flute end mills have only two teeth. The end teeth are designed so that they can cut to the center of the mill. Therefore, two-flute end mills may be fed into the work like a drill; they then may be fed lengthwise to form a slot.

Depth of cut at milling of key slot t = D = 8 mm. Maximal width is used about $b \approx 0.5 \times D = 0.5 \times 8 = 4$ mm,

Maximal feed rate for one teeth S_z is chosen in accordance with rigidness of mill (diameter of mill Ø8 mm), cutting tool material (HSS P6M5), processable material (steel 40X), surface roughness of slot sides (Ra < 6.3 μm) and recommendations which are given in tab. 38 [1, page 286] for two-flute mills (quantity of teeth z = 2): axial feed rate $S_{z\ ax} = 0.007$ mm per tooth, lengthwise feed rate $S_{z\ lw} = 0.022$ mm per tooth.

The **cutting speed** at milling is calculated by the formula:

$$V = \frac{C_V \cdot D^q}{(T^m \cdot t^x \cdot s_z^{\ y} \cdot B^u \cdot z^p)} \cdot K_V \quad , \qquad (6.19)$$

Where: T - cutting tool life (at key slot milling T=80 minutes, tab. 40 [1, page 290]).

Values of factor C_V and parameters of a degree for a two-flute mills from HSS and milling with cooling in processable constructional steel (steel 40X) are given in tab. 39 [1, page 286]:

$C_V=46.7;\ q = 0.45;\ x=0.5;\ y=0.5;\ u=0.1;\ p=0.1;\ m=0.3.$

K_V - correction factor:

$$K_V = K_{Mv} \times K_{\Pi v} \times K_{Иv}\ , \qquad (6.20)$$

where $K_{Mv} = 75/\sigma_в$ - factor which is taking into account influence of quality of a processable material (durability) on cutting speed. For steel 40X strength of a stretching $\sigma_в=75$ kg / mm^2, therefore $K_{Mv} = 75/\sigma_в = = 75/75 =1$;

$K_{Иv}$ - factor which taking into account material of a cutting part. For a cutting tool from HSS P6M5 $K_{Иv}$ =1 [1, page 263, tab.6];
$K_{Пv}$ =1 - factor which is taking into account a blank surface condition [1, page 263, tab.5].

$$K_V = 1 \times 1 \times 1 = 1.$$

$$V = \frac{C_V \cdot D^q}{(T^m \cdot t^x \cdot s_z^{\ y} \cdot B^u \cdot z^p)} \cdot K_V = \frac{46.7 \cdot 8^{0.45}}{(80^{0.3} \cdot 8^{0.5} \cdot 0.022^{0.5} \cdot 6^{0.1} \cdot 2^{0.1})} \cdot 1 = 59.5 \text{ mpm.}$$

We calculate number of revolutions of a spindle n_{cal}:

$$n_{cal} = \frac{1000 \cdot V}{\pi \cdot d_{mill}} = \frac{1000 \cdot 59.5}{3.14 \cdot 8} = 2368 \text{ rpm},$$

Where d_{mill} –diameter of mill, mm.

In the technical passport of the machine tool we look for the nearest number of revolutions of the spindle to our calculated figure (should be lesser because even an insignificant increment in the cutting speed can result in an evident reduction in cutting tool life *T*): $a_{ccepted}$ = 1000 rpm because our milling machine ФУ 521 has 1000 rpm as its highest which makes 1000 rpm the nearest number of revolution of the spindle to our $n_{cal.}$. We calculate the ***real*** (specified or corrected) ***cutting speed*** at the accepted number of revolutions of a spindle by the formula (7.6):

$$V_r = \frac{\pi \cdot d \cdot n_{accepted}}{1000} = \frac{3.14 \cdot 8 \cdot 1000}{1000} = 25.12 \text{ mpm.}$$

Calculation of **tangential component of cutting force** P_z [N], at milling is done by the formula

$$P_z = \frac{10 \cdot C_p \cdot t^x \cdot s_z^y \cdot B^u \cdot z}{D^q \cdot n^w} \cdot K_{mp} . \qquad (6.21)$$

Values of factor C_V and parameters of the degree for an end mill from HSS and milling in process able constructional steel (steel 40X) are given in tab. 41 [1, page 291]:

$$C_p=68.2; \; q = 0.86; \; x=0.86; \; y=0.72; \; u=1; \; w=0.$$

K_{mp} - correction factor:

$$K_{mp} = K_{Mp} \times K_{Пp} \times K_{Иp} , \qquad (6.22)$$

where $K_{Mp} = 75/\sigma_в$ - factor which is taking into account influence of quality of a processable material (durability) on cutting speed. For steel 40X strength of a stretching $\sigma_в=75$ kg / mm^2, therefore $K_{Mv} = 75/\sigma_в = = 75/75 =1$;
$K_{Иp}$ - factor which taking into account material of a cutting part. For a cutting tool from HSS P6M5 $K_{Иp}$ =1 [1, page 263, tab.6];
$K_{Пp}$ =1 - factor which is taking into account a blank surface condition [1, page 263, tab.5].

$$K_V = 1 \times 1 \times 1 = 1.$$

$$P_z = \frac{10 \cdot C_p \cdot t^x \cdot s_z^y \cdot B^u \cdot z}{D^q \cdot n^w} \cdot K_{mp} = \frac{10 \cdot 68.2 \cdot 8^{0.86} \cdot 0.022^{0.72} \cdot 6^1 \cdot 2}{8^{0.86} \cdot 1000^0} \cdot 1 = 524 \text{ [N]}.$$

Other components of cutting force are calculated by the ratios [1, page 292, table 42]:

$P_h : P_z = 0.3 – 0.4$; $P_h = P_z \cdot 0.4 = 524 \cdot 0.4 = 209.6$ [N];

$P_v : P_z = 0.85 – 0.95$; $P_v = P_z \cdot 0.95 = 524 \cdot 0.95 = 497.8$ [N];

$P_y : P_z = 0.3 – 0.4$; $P_y = P_z \cdot 0.4 = 524 \cdot 0.4 = 209.6$ [N];

$P_x : P_z = 0.5 – 0.55$; $P_x = P_z \cdot 0.55 = 524 \cdot 0.55 = 288.2$ [N];

The ***cutting power*** at milling key slot 8H9 **is** calculated by the formula (6.5):

$$N = \frac{P_z \cdot V}{1020 \cdot 60} = \frac{524 \cdot 25.12}{1020 \cdot 60} = 0.215 \text{ kW}.$$

Where P_z - tangential component of cutting force, N
V - Cutting speed, mpm.

7. TECHNICAL FIXING of LABOURIOUSNESS

As it was already noted, the manufacturing operation is the main element of the manufacturing process. Time and cost of the operation are an important criterion of its effectiveness for a given production plan.

Production plan is a list of products, for a given enterprise, that are manufactured or repaired with the specified production volume for a planned period of time. ***Production volume N*** is the amount of products of certain types, sizes and designs, manufactured or repaired by the enterprise within the planned period of time (usually – during **one year**). **Volume of production** is crucial for the **manufacturing process planning** and **layout**.

For a given volume of production the products, in most cases, are manufactured in batches or lots.

The ***production batch*** is the portion of products that is launched **simultaneously** into manufacture in a certain period of time. Production batch or its part that is de-livered to the workplace for machining operation is called operation batch.

Any manufacturing operation requires a certain amount of working time of equipment and workers. Calendar period of time **from the start to the end of the operation**, regardless of the number of simultaneously machined or repaired products, is called the ***operation cycle***.

The period of time equal to the ratio of the operation cycle to the number of simultaneously machined or repaired products or equal to calendar time of assembling operation is called the ***operation cycle per part*** *(OCPP)* $\mathbf{t_{oc}}$.

In non-automated production the OCPP is defined by the following equation

$$t_{oc}= t_m+t_a+t_w+t_r$$

where t_m is the machining time; t_a is the auxiliary time; t_w is the workplace maintenance time; t_r is the worker rest time.

The ***machining time*** is spent on the change and (or) the subsequent definition of the state of the subject of labour. This time can be of machine, machine-manual or manual type. The machining time for each processing step is calculated as follows:

$$t_m=L\cdot i/s_m,$$

where L is the estimated cutting distance (length of the cutting tool travel, mm); i is the number of passes of the given processing step; s_m is the feed rate of the cutting tool in mm/min.

With the manual feed of the cutting tool to the workpiece:

$$L = l+l_{en}+l_{ov} ,$$

where l is the length of the surface to be machined; l_{en} is the distance of cutting tool engagement with the workpiece; l_{ov} is the tool over-travel distance.

For the automatic machining cycle:

$L = l + l_{en} + l_{ov} + l_{ap}$

where l_{ap} is the distance of the tool approach to the workpiece in order to avoid collision in the beginning of machining.

The length l is found with the help of the drawing, the distances of engagement and overtravel are commonly taken equal to 1 mm. The value of the length of engagement is found geometrically. For longitudinal turning $l_{en} = t \cdot tg\varphi$, where t is the depth of cut; φ is the cutting edge angle. For drilling with standard twist drills $l_{en} = 0.3 \cdot d_c$, , where d_c is the diameter of the drill. For slot milling with a slotting milling cutter $l_{en} = [t \cdot (d_m - t)]^{1/2}$, where d_m is the milling cutter diameter.

Auxiliary time is the part of the OCPP (t_{oc}) required to perform actions needed to ensure changes and the subsequent definition of the state of subjects of labour. Auxiliary time is spent on loading, clamping and unloading of the workpiece or the component of the unit being assembled, operating the machinery, feeding the cutting tool to the workpiece and its withdrawal, measurement of the workpiece, etc. Auxiliary time can be defined as the amount of time for all the auxiliary steps of the operation. The time needed for the execution of the i^{th} auxiliary step t_{ai}, which is a set of m actions is calculated as:

$$t_{ai} = \sum_{j=1}^{j=m} t_{aj},$$

where t_{ai} is the time needed for the j^{th} action. The time needed for each action is specified according to the auxiliary time standards, which take into account specific conditions of the operation.

The sum of machining time and auxiliary time is called ***operation time*** t_{op}. It should be noted that only the portion of the auxiliary time that is **not overlapped** by the machining time is included into the t_{op}. For example, during the drilling operation, loading, clamping and unloading of workpieces is performed during the machining in positions *II* and *III*, so the time spent on these activities should not be included into the operation time.

Workplace maintenance time is a part of OCPP spent by a worker to service the manufacturing equipment and maintain it and the workplace in working condition. It is commonly accepted to distinguish between ***equipment maintenance*** time t_e and ***workplace preparation*** time t_{wp}, i.e. consider that:

$$t_w = t_e + t_{wp}$$

Equipment maintenance time *(EMT)* t_e is spent on changing blunt cutting tools, adjusting machinery, chip cleaning and swarf (chip) removal from the machining area. The EMT is taken in percents (up to 6%) of the operation time or machining time or taken according to standards depending on the type of work performed.

Workplace preparation time *(WPT)* t_{wp} includes the time required for cleaning and preparing the workplace for work, lubricating the machine at the end of the shift and other similar actions during the shift. This time is taken as a percentage of the operation time (0.6 ... 8%).

Rest time t_r is spent on the personal needs of a worker and on breaks during tedious work. This time is also taken as a percentage of operation time (about 2.5%).

In practical calculations, OCPP is calculated by the simplified equation:

$$t_{oc} = t_{op} \cdot [1+(\alpha+\beta+\gamma)/100],$$

where α, β, γ – the ***EMT***, ***WPT*** and **rest** time, respectively, **in percentage** of the operation time. Values for α, β, γ are taken according to the standard times.

For the automatic equipment the OCPP is determined by the following equation:

$$t_{oc} = t_{op} \cdot [1+\alpha/100].$$

When parts are manufactured in **batches**, the ***set-up time*** t_s is calculated. **Setup time** is defined as a period of time, spent on the preparation of the performer or performers and technological means for manufacturing operation and bringing these means in order after the end of the **shift** and (or) operation performed for the batch of subjects of labour. Set-up time is spent by a worker to ***get acquainted*** with drawings and technical documentation, to prepare and set-up the equipment, tools and fixtures, to remove and deliver cutting tools and fixtures to the store room after manufacturing a batch of parts.

The time spent to manufacture a batch of parts on the operation is:

$t_r = t_s + t_{oc} \cdot n$

n is the number of parts in the batch.

Allocation of hours required to perform certain operations and manufacturing process as a whole is one of the most important tasks of the *manufacturing resource planning*, which implies defining technically sound standards of resources consumption (work time, materials, tools, etc.).

Standard time is a regulated time for performing amount of work in certain production conditions by one or several workers of appropriate qualification.

It is common to distinguish between standard times for operation cycle per part, operation time, machining time, auxiliary time and set-up time.

If the products are manufactured continuously, then the standard time of the OCPP t_{oc} is used as the standard time H_t for an operation, i.e.:

$H_t = t_{oc}$

If the products are manufactured **in batches**, then the sum of the OCPP t_{oc} and portion of the setup time t_s per one part of a batch is used as the standard time H_t for the operation, i.e.:

$H_t = t_{oc} + t_s/n$

The **reciprocal of the standard time** (1/ H_t) is called ***the standard production rate***. ***Standard production rate*** is the rated amount of work that must be performed per unit of time in certain organizational and technical conditions, by one or more workers of appropriate qualification. Production rate can be expressed, for example, in a number of workpieces to be machined per unit of time.

To determine standard time the following three methods are used:

– method of calculations according to the technical standard times;

– method of calculation based on observation of working time;

– method of comparison and calculations based on extended standard time.

Standard time is set based on the analysis of the composition of actions of the worker and production equipment at its most advantageous use.

In the **first** method a standard time for an operation is calculated based on elements of work with the use of standards which specify the estimated time needed to perform these elements of work. In the **second** method the standard time is set based on the time study of the working process, which is observed directly in the production environment. Commonly, two basic methods of time study by observation are distinguished: the ***work sampling*** and ***workday time study***. During the **work-sampling** the attention is focused on measuring the time spent on manual and machine-manual elements of the operation (for example, time spent on mounting and clamping a workpiece) to basic times for these elements, as well as to develop on this basis, the relevant standard times. **Workday time study** involves measurement of working time during a **shift** or several shifts. Its main purpose is to determine **losses of working time**, to set standard time for workplace maintenance and breaks. In the **third** method standard time is determined **approximately** by the extended standard times, which are developed on the basis of comparison and calculation of typical operations.

Different goods of mechanical engineering manufacture are produced in **different quantities** depending on the requirements. Some goods are produced in a single copy; the others are produced in hundreds of thousands.

Three methods of manufacturing can be distinguished, depending on the variety and **volume of production**. These methods are **job production, batch production** and **mass production. Batch production** is subdivided into ***small-batch*** production, ***medium-batch*** production and ***large-batch*** production.

Method of production is defined according to ***production factor*** k_{pf} that is the **ratio** of **number of all different operations** done or to be done **during a month** to the **number of working places**. In other words, this factor shows the **average amount of operations done or to be done for the one working place during a month**. Production factor is: 1 for **mass production**; from **1 to 10** for **large-batch production**; from **10 to 20** for **medium-batch production**; from **20 to 40** for **small-batch production**; **40 and more** for **job production**.

Job production is characterized by a small volume of outputting similar products. Their remanufacturing and repairing are, as a rule, not planned. Job products are machines of restricted application (prototype machines, large hydro-turbines, unique machine tools, roll mills etc.).

The characteristic feature of job production is performing (at working places) the great number of various operations that may never be repeated. Job production should be very flexible in this connection. **General-purpose equipment** and **standard production fixtures** are used in job production. Equipment in workshops is arranged according to its type (a turning machines sector, a milling machines sector, etc.). Manufacturing processes **are not usually developed in detail**. Qualification of the most workers in job production is high.

Batch production is characterized by manufacturing or repairing products in **periodically repeated** batch lots. Products produced in batches are steady state machine types (metal cutting machine tools, wood-working machine tools, pumps, compressors, aviation engines, etc.) manufactured in significant quantities. This method of production is the most widespread (**75-80 per cent** of all the products of mechanical engineering are batch products).

The characteristic feature of batch production is relatively small amount of periodically repeated operations (at working places). **Both special fixtures** and tools and **universal fixtures** and tools are used in batch production. Equipment in the workshops is arranged according to the manufacturing process or according to its type (small-batch production). **Manufacturing processes** in batch production **are developed in details**. **Qualification** of the most workers is in general lower than in job production but **it is still high**, for example, for operating the CNC machines.

Mass production is characterized by a large volume of outputting products, manufactured or repaired continuously for a long period of time, during which one operation is done at the majority of working places. Mass products are products for the wide range of customers (automobiles, tractors, low-power electric motors, rolling bearings, etc.).

Special high-performance equipment and **production accessories** are used in mass production. As a rule, **equipment** in workshops **is arranged strongly according to the manufacturing process**. Manufacturing processes in mass production are developed in considerable details. Qualification of the most workers is in general low but **highly-qualified service engineers** are required.

Subdividing the production into the methods is, in a way, relative and is done according to the predominate production. For example, production of bearings in a ball bearing plant is mass. Job production does take place in a repairing shop of the factory.

Two methods of operation are applied in mechanical engineering: ***flow production*** and ***non-flow production***. Flow production is characterized by arranging the equipment according to the sequence of operations in the manufacturing process and definite time intervals of products output. The time interval, during which products or workpieces of certain names, standard sizes and modifications are periodically issued is called ***Takt time***

$t_d = F_a / N,$

where F_a – actual available hours of equipment operation in the scheduling period (a **year**, a month, a day, a shift, an hour); N – the volume of production for the same period.

Nominal annual available hours of equipment operation is 2070 hours for **one-shift** work, 4140 hours for **two-shift** work and 6210 hours for **three-shift** work. ***Actual annual*** available hours of equipment operation (with regard to loss of time for equipment repair) for one-, two- and three-shift work is **2030, 4015** and **5965** hours, respectively.

In flow production, the work is performed on the production line. In general, the condition for organizing the flow is the multiplicity of time for each manufacturing operation to the **Takt time** t_d:

$t_d = t_{oc} / k\ (1, 2, 3, ..i)$,

where t_{oc}– operation cycle per part of i^{th} manufacturing operation.

Bringing the times of operations to the required condition is called *production flow* ***synchronisation***. It is achieved by the corresponding sequencing of manufacturing operations and sometimes by using the so-called doubling machine tools, i.e., for example, using not one but two machines for some operations. One **product rolls off** a flow line for the time equal to Takt time.

The **amount of products** or workpieces of certain types, sizes and modifications manufactured **per time unit** is called ***production rate***. Ensuring the given production rate is the most important task in planning of manufacturing processes in mass and large-batch productions.

It is often impossible to organize flow production for the manufactured products in batch production due to low use of equipment for small volumes of output. In this case the variant of a flow method of production, called ***flexible flow-production***, is used.

In flexible flow-production, each machine on the production line performs a set of operations. During a definite period of time (usually several shifts), machining of workpieces of the same size is performed on the line. Then the line is readjusted for machining workpieces of the other size, etc.

Flow production can:

- reduce production cycle considerably (in dozen times);
- reduce inter-operational buffers and work-in-process;
- apply high-performance equipment and reduce labour intensity of production;
- simplify production control.

In case of small volume of production, **non-flow production** is used. It is used in batch and job productions. In non-flow production operation time **is not synchronized. Buffers of workpieces** (assembly units) that **are necessary** for workplace capacity are created at workplaces. In non-flow production, the **maximal technological action** upon the subject of labour is tended to be done at **every working place**, the amount of operations in manufacturing process is aimed to be reduced, that is to design the manufacturing operations on the basis of **concentration of processing steps**.

In non-automated production the **OCPP** (*operation cycle per part)* is defined by the equation:

$$t_{oc}= t_m+t_a+t_w+t_r\,.$$

Generally **machining** t_m and **auxiliary** t_a **time** is determined for each **processing step** but **time for workplace maintenance (service)** $\boldsymbol{t_w}$ of machine tool and **time for the rest** $\boldsymbol{t_r}$ is determined for whole technological operation.

The **standard time** H_t for the operation is defined by the equation:

$$H_t = t_{oc} + t_s/n$$

The accepted number of details in a batch is n_{ac} = 200 pieces.

We calculate machining, auxiliary, workplace maintenance, rest, ***set-up time (preparation***) t_s time for each operation and write them in tab. 7.1.

Operation 1 (blanked)

Processing step 2 (cutting off a blank with the length l = 56h16 from a rod having Ø55h16)

The basic time is calculated by the formula (8.4). Generally length of cutting (length in the direction of a feed rate S) is calculated by the formula:

$$L = d_{blank}/2 + l_{uc} + l_{oc}\text{ , mm.} \qquad (7.8)$$

On the basis of the recommendations [7, page 24] is accepted: $l_{uc} + l_{oc}$ = 5 mm.

$$t_m = \frac{L}{n \cdot S_r} = \frac{15+5}{630 \cdot 0.5/2} = 0.15 \text{ min.}$$

The auxiliary time is determined by the formula (8.7):

$$t_{aux} = T_l + T_c + T_o + T_m,$$

where T_l = *0.12min* - time for maintaining and fixing (loading) and unloading of a blank [1, tab.5.6, page 199];

T_c = *0.13min* - time for clamping of a blank [1, tab.5.7, page 201];

T_o. = *0.1 min* - time for operate (management) of the machine tool [1, tab.5.8, page 202];

T_m = *0.1 min* - time for measurements [1, tab.5.16, page 209].

$$T_{aux} = T_l + T_c + T_o + T_m = 0.12 + 0.13 + 0.1 + 0.1 = 0.45 \text{ min.}$$

Operative time is determined by the formula:

$$T_{op} = T_d + T_{awx},\ min. \tag{7.9}$$

$$T_{op} = T_d + T_{awx},= 0.15 + 0.45 = 0.6\ min.$$

Time for service of one workplace is determined by the formula:

$$T_s = 0.05 \cdot T_{op} = 0.05 \cdot 0.6 = 0.03 \text{ min.} \tag{7.10}$$

Time of breaks for rest and personal needs is determined by the formula:

$$T_r = 0.06 \cdot T_{op} = 0.06 \cdot 0.6 = 0.036 \text{ min.} \tag{7.11}$$

Floor-to-floor time (piece time) is determined by the formula (7.2):

$T_f = T_{op} + T_s + T_r$,= 0.6 + 0.03 + 0.036 = 0.666 min.

Floor-to-floor calculation time is determined by the formula (7.1):

$$T_{fc} = T_f + \frac{T_p}{n_s} = 0.666 + \frac{18}{400} = 0.666 + 0.045 = 0.711 \text{ min}$$

where T_p - preparation time, T_p = 18 min [1, tab. 6.4, page 216]; n_s - quantity of parts in a set, n_s = 400 pieces.

The calculations of the time for different operations are written below.

Operation 02 (lathered)

Processing step 2 (turn off the right end face of a blank with the length *l* = 52.9h14)

Generally length of cutting is calculated by the formula (7.8):

$$L = d_{blank}/2 + l_{uc} + l_{oc} = 30/2 + 2 + 0 = 17 \text{ mm.}$$

The basic time is calculated by the formula (7.4).

$$T_d = \frac{L}{n \cdot S_r} = \frac{17}{1000 \cdot 0.5/2} = 0.068 \text{ min.},$$

where S_r = 0.5 mmpr - is adjusted feed rate on the gear box, but this feed rate is divided on 2 when we take on the **cross** feed rate; n =1000 rpm (from the previous calculation of cutting speed for the rough turning of the external surface with size 30h11).

The auxiliary time is determined by the formula (7.7):

$$T_{aux} = T_l + T_c + T_o + T_m = 0.12 + 0.13 + 0.1 + 0.2 = 0.55 \ min.$$

where $T_l = 0.12min$ - time for maintaining and fixing (loading) and unloading of a blank [1, tab.5.6, page 199];

$T_c = 0.13min$ - time for clamping of a blank [1, tab.5.7, page 201];

$T_o. = 0.1 \ min$ - time for operate (management) of the machine tool [1, tab.5.8, page 202];

$T_m = 0.2 \ min$ - time for measurements [1, tab.5.16, page 209].

$$T_{aux} = T_l + T_c + T_o + T_m = 0.12 + 0.13 + 0.1 + 0.1 = 0.45 \ min.$$

Processing step 3 (center hole drilling on the right end face of the blank)

The basic time is calculated by the formula (7.4).

$$T_d = \frac{L}{n \cdot S_r} = \frac{15}{1000 \cdot 0.1} = 0.15 \text{ min.}$$

The auxiliary time is determined by the formula (7.7):

$$T_{aux} = T_l + T_c + T_o + T_m = 0 + 0 + 0.3 + 0 = 0.3 \ min.$$

where $T_l = 0 \ min$ - there is no time for maintaining and fixing (loading) and unloading of a blank (we have taken it into account in the second technological transition);

$T_c = 0 \ min$ - there is no time for clamping of a blank (we have taken it into account in the second technological transition);

$T_o. = 0.3 \ min$ - time for operate (management) of the machine tool: to maintain a center drill, to move the tailstock of a lathe close to the right end face of the blank; to return on the feed rate from 0.5 mmpr to 0.1 mmpr; to turn on the feed rate [1, tab.5.8, page 202];

$T_m = 0 \ \ min$ - there is no time for measurement (it is need not to measure the length and diameter of center hole because we shall drill the hole with Ш17.5H14.

Processing step 4 (hole drilling with Ø17.5H14)

The basic time is calculated by the formula (7.4).

$$T_d = \frac{L}{n \cdot S_r} = \frac{52.9 + 0 + 10}{125 \cdot 0.43} = 1.263 \text{ min.}$$

The auxiliary time is determined by the formula (7.7):

$$T_{aux} = T_l + T_c + T_o + T_m = 0 + 0 + 0.3 + 0 = 0.3 \ min.$$

where $T_l = 0\ min$ - there is no time for maintaining and fixing (loading) and unloading of a blank (we have taken it into account in the second technological transition);

$T_c = 0\ min$ - there is no time for clamping of a blank (we have taken it into account in the second technological transition);

$T_o. = 0.3\ min$ - time for operate (management) of the machine tool: to maintain a drill with Ш17.5, to move the tailstock of a lathe close to the right end face of the blank; to return on the feed rate from 0.1 mmpr to 0.43 mmpr; to turn on the feed rate [1, tab.5.8, page 202];

$T_m = 0\ \ min$ - there is no time for measurement (it is need not to measure the length and diameter of center hole because we shall bore the hole with Ш19.5H11.

Processing step 5 (hole boring with Ø19.5H11)

The basic time is calculated by the formula (7.4).

$$T_d = \frac{L}{n \cdot S_r} = \frac{52.9 + 2 + 2}{2000 \cdot 0.21} = 0.133 \text{ min.}$$

The auxiliary time is determined by the formula (7.7):

$$T_{aux} = T_l + T_c + T_o + T_m = 0 + 0 + 0.3 + 0.1 = 0.4 \ min.$$

where $T_o. = 0.3\ min$ - time for operate (management) of the machine tool: to maintain a bore cutter, to move the bore cutter close to the right end face of the blank; to return on the feed rate from 0.43 mmpr to 0.21 mmpr; to adjust on the size Ш19.5H11; to turn on the feed rate [1, tab.5.8, page 202];

$T_m = 0.1\ \ min$ - time for measurement [1, tab.5.16, page 209].

Processing step 6 (boring the chamfer with size 3.5J_s15 on the right end of the bored hole)

The basic time is calculated by the formula (7.4).

$$T_d = \frac{L}{n \cdot S_r} = \frac{3.5}{2000 \cdot 0.1} = 0.016 \text{ min.}$$

The auxiliary time is determined by the formula (7.7):

$$T_{aux} = T_l + T_c + T_o + T_m = 0 + 0 + 0.1 + 0.1 = 0.2 \ min.$$

where T_o. = *0.1 min* - time for operate (management) of the machine tool: to move the bore cutter close to the right end face of the blank; it is need not to turn on the feed rate because we do it manually [1, tab.5.8, page 202];
T_m = *0.1 min* - time for measurement [1, tab.5.16, page 209].

Operative time of ***operation 02*** is determined by the formula (7.9):

$$T_{op} = \sum(T_d + T_{awx}) = (0.068 + 0.55) +(0.15 + 0.3) +(1.263 + 0.3) +(0.133 + 0.4)+ +(0.016 + 0.2) = 3.38\ min.$$

Time for service of one workplace is determined by the formula (7.10):

$$T_s = 0.05 \cdot T_{op} = 0.05 \cdot 3.38 = 0.169 \text{ min.}$$

Time of breaks for rest and personal needs is determined by the formula (7.11):

$$T_r = 0.06 \cdot T_{op} = 0.06 \cdot 3.38 = 0.203 \text{ min.}$$

Floor-to-floor time (piece time) is determined by the formula (7.2):
$T_f = T_{op} + T_s + T_r$,= 3.38 + 0.169 + 0.203 = 3.752 min.

Floor-to-floor calculation time is determined by the formula (7.1):

$$T_{fc} = T_f + \frac{T_p}{n_s} = 3.752 + \frac{18}{400} = 3.752 + 0.045 = 3.797 \text{ min}$$

where T_p - preparation time, T_p = 18 min [1, tab. 6.4, page 216]; n_s - quantity of parts in a set, n_s = 400 pieces.
The calculations of the basic time for different operations are written in table 7.1.

Table 7.1. Calculation of laboriousness of shaft manufacturing

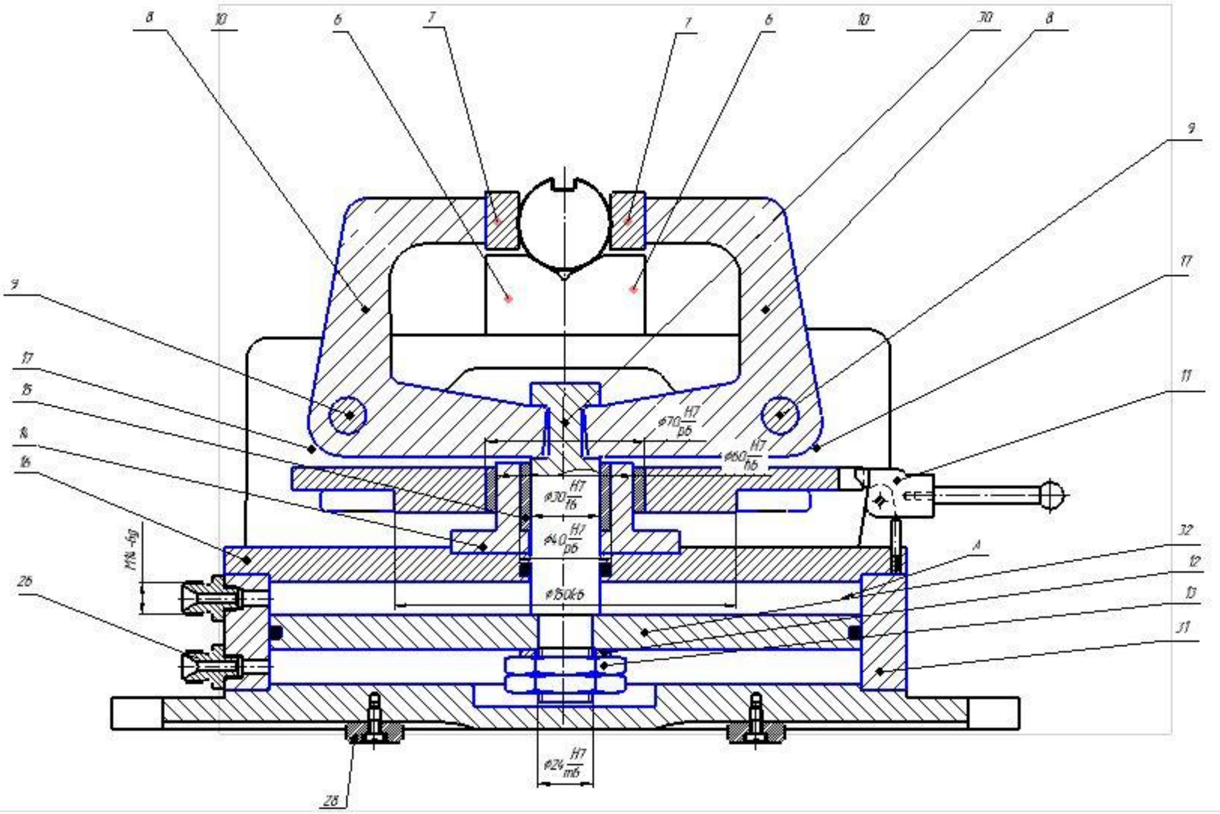
Number		Modes		Length	Time, min				$T_{op,}$	$T_{s,}$	$T_{r,}$	$T_{f,}$	$T_{p,}$	$T_{fc,}$
Op.	Proc. step	n, rpm	S, mmpr	L, mm/ dia-meter d, mm	T_m	T_i+ T_{fast}	T_o	T_m	min	min	min	min	min	min
1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***
01	1					0.25			0.6	0.03	0.04	0.67	18	**0.71**
	2	630	0.21	20	0.15	---	0.1	0.1						
02	1					0.25			3.38	0.17	0.2	3.75	18	**3.8**
	2	1000	0.5/2	20	0.07	---	0.1	0.1						
	3	1000	0.1	15	0.15	---	0.3	0						
	4	125	0.43	68	1.26	---	0.3	0						
	5	2000	0.21	55	0.13	---	0.3	0.1						
	6	2000	0.1	3.5	0.02	---	0.1	0.1						
03	1					0.25			1.5	0.08	0.09	1.67	18	**1.72**
	2	1000	0.5/2	20	0.07	---	0.1	0.1						
	3	1000	0.5	54	0.11	---	0.1	0.1						
	4	2000	0.11	54	0.25	---	0.1	0.1						
	5	2000	0.1	3.5	0.02	---	0.1	0.1						
04	1					0.25			0.51	0.03	0.03	0.57	18	**0.62**
	2	2000	0.1	11	0.06	---	0.1	0.1						

1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***
05	1 2	Quenching HRC 50…55 a set of parts (200 pieces) by heating at temperature 850…890ºC during 60 min and then cooling in oil Industrial 40 at temperature 20…30ºC							0.4	0.02	0.02	0.44	30	**0.**52
06	1					0.25	0.1	0.1	0.63	0.03	0.04	0.7	30	**0.78**
	2	n_{gr} = 2350 n_{part}= 300	12.5;	80/250 t=0.03 mm; $2\cdot z_{max}$= 0.221 mm.	0.02 ×i= 0.02 ×5× 2 = = 0.2	---								
07	A1					0.25			1.65 + 0.7= 2.35	0.12	0.14	2.61	30	**2.69**
	2	n_{gr} = 2350	S_l =20 mpm, S_{cr}= 0.2·B = 0.2·20 =4 mmpp	50/250 t=0.03 mm; $2\cdot z_{max}$= 1.19 mm.	0.003×10 ×i= 0.03 ×40 = 1.2	---	0.1	0.1						
	B 3					0.25								
	4	n_{gr} = 2350	S_l =20 mpm, S_{cr}= 0.2·B = 0.2·20 =4 mmpp	50/250 t=0.03 mm; $2\cdot z_{max}$= 0.462 mm.	0.003×10 ×i= 0.03 ×17 = 0.51	---	0.1	0.1						
	5					0.25								
08	1					0.25			1.49	0.08	0.09	1.66	30	**1.74**
	2	n_{gr} = 2350 n_{part}= 300	12.5;	80/15 t=0.01 mm; $2\cdot z_{max}$= 0.521 mm.	0.02 ×i= 0.02 ×26 ×2 = = 1.04	---	0.1	0.1						
09							2.5							**2.5**

Total calculated floor-to-floor time of technological process is calculated:

$\sum T_{fc}$ =0.71+3.8+1.72+0.62+0.52+0.78+0.375+2.69+1.74 +2.5=**15.455** min.

8. Design Section



The aim is to design a suitable attachment for a mechanical part which we are going to manufacture. We will mill both ends of the shaft, which will be lying in two prisms. The angle of the prisms is 90 degrees. On the scheme is shown the pneumatic attachment of the shaft gripped in prisms.
We have to calculate the required force for our attachment and also the force we will get by pneumatic mechanism. Piston force has to be much higher than required force.

1. **Given and chosen:**

Diameters required for calculations:

$d_1 = \emptyset\ 34h16$
$d_2 = \emptyset\ 24h16$
$d_3 = \emptyset\ 44h16$

Friction:

$f_3 = f = 0{,}1$

Feed rate:

$S_z = 0{,}09 \dots 0{,}18 \ \rightarrow 0{,}1 \text{ mm/tooth}$

Time of machining:

$T = 150 \text{ min}$

Torsional strength of material - steel:

σ_{tor} 1000 MPa

Pressure in cylinders of pneumatic mechanism:

$p = 0{,}4\text{MPa}$

2. Calculations:

Diameter of a milling cutter:

$$d_{mill} = 2 * \left(\frac{d_3}{2} + t_1 + t_{safe} + \frac{d_3}{2} + \frac{d_1}{2}\right) = 2\left(\frac{40}{2} + 10 + 10 + \frac{44}{2} + \frac{34}{2}\right) = 158\ mm$$

$d_{mill} \geq 158\text{mm}$

We are choosing a milling cutter ГОСТ **5348-69 ø160mm**

Hole - $d = 40 \text{ mm}$

Big diameter - $D = 160 \text{ mm}$

Width - $B = 15 \text{ mm}$

Teeth - $Z = 12$

T15K6

Maximum machined thickness:

$Z_{12\,max} = Z_{12min} + T_{A01} + T_{A12} = 0{,}81 + 2{,}9 + 1{,}15 = 4{,}86 \approx 4{,}9 \text{ mm}$

Cutting speed:

$$v = \frac{c_v * D^{cv}}{T^m * t^x * S_z^y * B^u * Z^p} * K_v = \frac{1340 * 160^{0,2}}{150^{0,35} * 34^{0,4} * 0{,}1^{0,12} * 4{,}9^0 * 12^0} * 0{,}57 = 117 \text{ m/min}$$

$K_v = K_{mv} * K_{nv} * K_{uv} = 0{,}71 * 0{,}8 * 1 = 0{,}57$

$K_{nv} = 0{,}8$

$$K_{mv} = K_g * \left(\frac{750}{\sigma_{tor}}\right) = 0{,}95 * \left(\frac{750}{1000}\right)^1 = 0{,}71$$

$K_{uv} = 1$

Frequency of revolution:

$$n_{calc} = \frac{1000 * v}{\pi * d_{mill}} = \frac{1000 * 117}{\pi * 160} = 212{,}6 \text{ r/min}$$

$n_{acc} = 200 \text{ r/min}$

Feed rate of milling cutter:

$S_m = S_z * Z * n_{ace} = 0{,}1 * 12 * 200 = 240 \text{ mm/min}$

Force in z axis:

$$P_Z = \frac{10 * c_p * t^x * S_Z^y * B^u * Z}{D^{cv} * n^w} * K_{mp} = \frac{10 * 261 * 34^{0,9} * 0,1^{0,8} * 4,9^{1,1} * 12}{160^{1,1} * 200^{0,1}} * 1,09 = 1615 \text{ N}$$

$$K_{mp} = (\frac{\sigma_{tor}}{750})^{np} = \left(\frac{1000}{750}\right)^{0,3} = 1,09$$

Gripping force:

$$W = \frac{K * M_{torsiom}}{r\left(f * \sin\frac{\alpha}{2} + f_3\right)} = \frac{2 * 27,45}{17\left(0,1 * \sin\frac{90}{2} + 0,1\right)} = 18,9 \approx 20 \text{ N}$$

$$M_{torsion} = P_Z * \frac{d}{2} = 1615 * \frac{34}{2 * 1000} = 27,45 \text{ Nm}$$

Torque equation:

$$W * l_2 = Q_{req} * l_1$$

$$Q_{req} = \frac{W * l_2}{l_1} = \frac{20 * 90}{60} = 30 \text{ N}$$

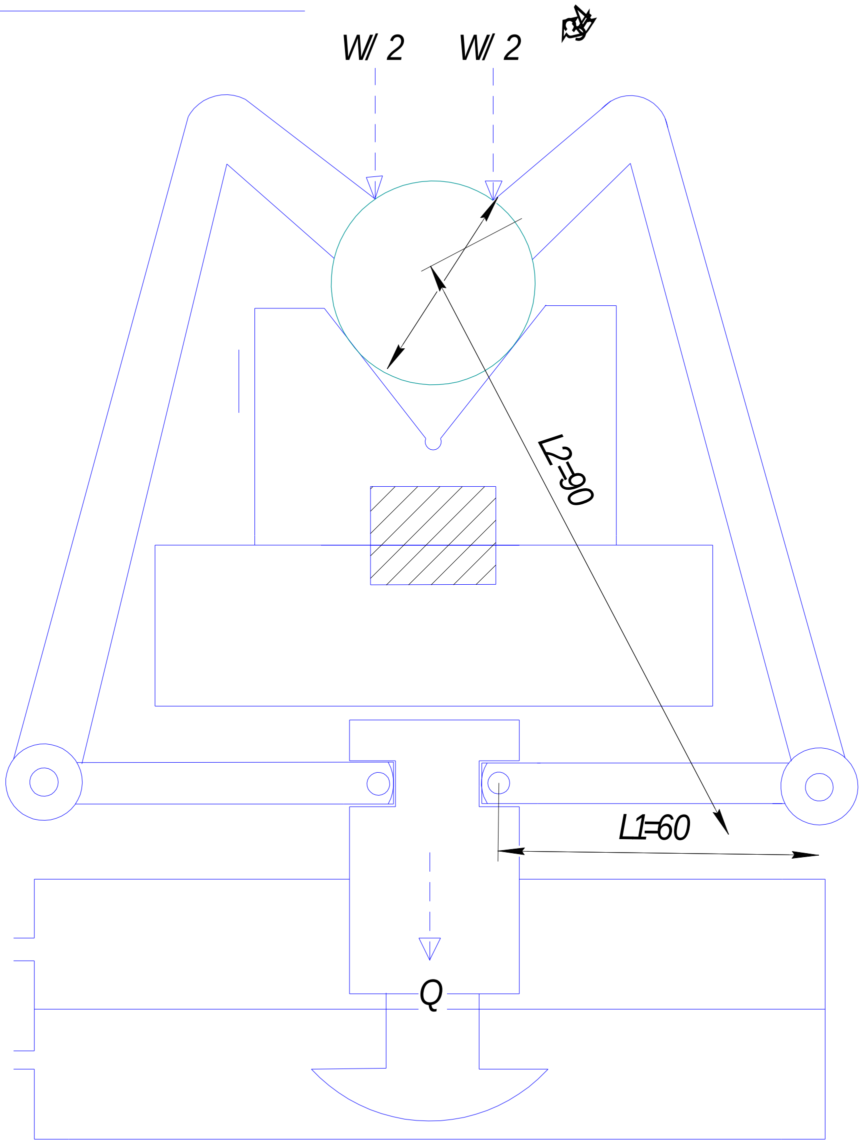
Pascal law in cylinders (pressure in cylinder):

$$Q_{piston} = \left(\frac{D^2 * \pi}{4} - \frac{d^2 * \pi}{4}\right) * p = \left(\frac{0,25^2 * \pi}{4} - \frac{0,03^2 * \pi}{4}\right) * 0,4 * 10^6 = 19352 \text{ N}$$

$$Q_{piston} \gg Q_{req}$$

3. Conclusion:

We figured out that the force of pistons (Q_{piston}) which we are going to get is much higher than the required force (Q_{req}). Although the piston force is much higher we are not going to change parameters of pneumatic mechanism. The reason is that if there will be some oil the coefficient of friction will dramatically change and required force will be higher. Also our attachment might be used for a harder material that shown in calculations.



Перв. примен.
Справ. №
Подп. и дата
Инв. № дубл.
Взам. инв. №
Подп. и дата
Инв. № подл.

Изм. Лист | № докум. | Подп. | Дата
Разраб.
Пров.
Т.контр.
Нконтр.
Утв.

Лит | Масса | Масштаб
1:1
Лист | Листов 1

Копировал
Формат A4

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