Ministry of Education and Science of Ukraine
Ternopil Ivan Pul'uj National Technical University
(full name of higher education institution)
Engineering of Machines, Structures and Technologies
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EXPLANATORY NOTE
for diploma project (thesis)

bachelor
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topic: **Improvement of the flange 753.172.004 machining production process**

Submitted by: fourth year student group IMP-42
Specialism (field of study)
131 «Applied Mechanics»
(code and name of specialism (field of study))

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Faculty *Engineeringof Machines, Structures and Technologies*
Department *Mechanical Engineering Technologies*
Educational degree *Bachelor*
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APPROVED BY
Head of Department *Okipniy IB*

Assignment

FOR DIPLOMA PROJECT (THESIS) FOR STUDENT

Tanoe Ezekiel Blay
(surname, name, patronymic)

1. Project (thesis) theme. **Improvement of the flange753.172.004 machining production process**

Project (thesis) supervisor *Prof., Vasylkiv VV*
(surname, name, patronymic, scientific degree, academic rank)

1.Approved by university order as 31.12.2021 № 4 / 7-1178
2. Student's project (thesis) submission deadline 24 th of June 2022
3. Project (thesis) design basis *Drawing of the part.*
Basic technological process. Annual production program.

4. Contents of engineering analysis (list of issues to be developed)
General-technical chapter. Analysis of part design and basic technological process of its manufacture.
Technological chapter. The choice of method of manufacture of the workpiece. Development of operational technological process. The calculation of the cutting conditions. Rate setting of operations.
Designing chapter. Choice and design description of attachments. Tools, materials and appliances for the manufacture of the case.
Safety measures.
5. List of graphic material (with exact number of required drawings, slides)
Flange (workpiece) - A1.
Routing technological process of manufacturing part - 3A1.
Technological attachment – 1A1.

6. Advisors of design (thesis) chapters

Chapter	Advisor's surname, initials and position	Signature, date	
		assignment given	assignment accepted
Safety measures	*Professor Valery Lazariuk*		

7. Date of receiving the assignment *25 th of June 2022*

PROJECT TIME SCHEDULE

LN	Diploma project (thesis) stages	Project (thesis) stages deadlines	**Notes**
1	*General-technical chapter*	*05.06.2022*	
2	*Technological chapter*	*06.07.2022*	
3	*Designing chapter*	*06.14.2022*	
4	*Safety measures*	*06.28.2022*	
5	*Drawings*	*07.04.2022*	

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Project (thesis) supervisor ______________ *Vasylkiv VV*
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ABSTRACT

The qualification paper topic: “Improvement of the flange 753.172.004 machining production process” Student of group IMP-42 of Ternopil Ivan Puluj National Technical University. Ezekiel Tanoe. Paper supervisor -Prof. Vasylkiv VV

Keywords: flange, technological process, operation, drilling, workpiece.

The purpose of the work is to improve the technology of making the flange753.172.004 with the appropriate justification.

To achieve this goal, the following tasks have been solved.

The first section analysis of part design and basic technological process of manufacturing flange, its application, technical requirements for surfaces, its manufacturability. We have considered in detail the basic technological process.

In the second section, the type of production was determined, the best option for making the workpiece was chosen - stamping. We synthesized the technological route of processing the part, determined the allowances and interoperative dimensions. We conducted a selection of tools, technological equipment and facilities. We calculated the cutting modes.

The third section presents the design and principle of operation of the device for simultaneous drilling of 5 holes., calculated their accuracy and power parameters. The fourth section deals with the issues of life safety and the basics of labor protection.

The relevant conclusions and the list of references are presented.

The annexes provide the technological process of manufacturing the flange753.172.004 and the specifications to the graphic part.

CONTENT

INTRODUCTION

In the qualification work of the bachelor improved the technological process of mechanical processing of the flange 753.172.004.

In the basic technological process of machining of the flange parts 753.172.004, the following basic parameters are used at the enterprise for serial production: universal debug devices are used for machining parts as technological equipment; universal metal-cutting equipment of normal accuracy is used; the use of universal measuring tools to control the accuracy and roughness of treated surfaces; the use of universal standard cutting tools for machining blanks; the concentration of operations of the basic technological process corresponded to the serial type of production.

1 GENERAL TECHNICAL PART

1.1 Purpose, characteristics and analysis of technical requirements for the flange 753.172.004.

Part 753.172.004 - flange belongs to the class of rotating bodies. It is included in the sprayer fan assembly. The flange in the assembly is mounted on rolling bearings - bearings, which in turn are mounted on the half-axis. A fan disk is attached to the flange.

The main surfaces of the part are: a hole for bearings, the end to which the disk is attachedfan, holes for mounting lids.

In the central part of the flange there is a stepped hole Ø62 P7 and Ø72 P7, in which the half-axis is installed. Seating surfaces C and D are designed to accommodate bearings and is performed in accordance with the requirements of GOST 25346-82. The surface roughness of the central hole is - 0.8 mkm. The tolerance of the radial beating of the surfaces C and D relative to each other is 0.08 mm. Tolerance of diameters of diameters C and D in cross and longitudinal sections - 0,015 mm. At the ends there are eight threaded holes (four on each side) designed to attach lids with sealing elements. On a circle Ø175 five openings Ø18 + 0,035 which are intended for fastening of a disk of a wheel by means of bolts are symmetrically located. The location of these holes is set to the tolerance of the alignment with a deviation of not more 0.1 mm from the nominal, the base is the central axis of the part.

The considered detail is rigid enough, has convenient base surfaces and does not cause special technical difficulties at its processing.

The material for the manufacture of this part is gray cast iron brand DIN 1691 Grade GG-20. Analogues of this material are brandsSC 20 GOST 1412-79,A48-30B, Class30B, No.30, EN-GJL-200, EN-JL1030, FG20.The material of the part is characterized by good casting properties because the proportion of carbon that is included in the content of the material is in the form of graphite [1]. Graphite provides reduced hardness, good machinability of the material, as well as good antifriction properties (low coefficient of friction).

1.2 Analysis of the manufacturability of the design of the part

The design of a detail is technological because provides simple and economic production of a detail with the minimum expenses and high productivity, does not cause considerable complexity at receiving preparation, has considerable durability at processing.

All machined surfaces have free access to the cutting tool. The part does not undergo heat treatment, which could lead to its warping and the need for additional processing after hardening. The mounting bases are the central hole and the rear plane of the part.

The constructive form of a detail allows to fulfill the following requirements to manufacturability of machining:

- possibility of simple and reliable fastening of a detail on the machine;
- the missing holes are not perpendicular to the plane of the entrance tool;
- the shapes of surfaces and their sizes allow to carry out processing on the models of the metalworking machines let out by the machine-tool industry.

The part has six steps on the outside and five steps on the hole. The inner stages have a roughness class Ra 0.8 mkm (surfaces C and D, which are designed for bearing mounting). Two ends and five holes with a roughness of Ra 3.2 mkm. Eight threaded holes (four at each end).

In general, the part is quite technological, with its casting and machining there are no special difficulties, the part has a comfortable base surface. The use of high-performance cutting modes is allowed for machining.

Quantitative analysis of the manufacturability of the part

When conducting a quantitative analysis of the manufacturability of the part, we determine the following coefficients:

1. Coefficient of level of manufacturability on roughness. Coarse-bone ratio K_{sho}determined according to GOST 1402-73 and taken in the range from 0 to 1.

$$\text{Ksho} = \frac{1}{\text{B}_{\text{CP.}}}$$

where $B_{CP.}$. - the average class of roughness of processing of this detail;

$$\acute{A}_{\text{ÑÐ.}} = \frac{1n_1 + 2n_2 + 3n_3 + ... + 14n_{14}}{n_1 + n_2 + n_3 + + ... + n_{14}}$$

where 1 - 14 - classes of roughness of processing;

n1 - n14 - the number of surfaces of this class of roughness;

$$B_{CP.} = \frac{2\cdot 20 + 4\cdot 5 + 5\cdot 10 + 6\cdot 7 + 7\cdot 2 + 8\cdot 2}{20 + 5 + 10 + 7 + 2 + 2} = 3{,}96$$

$$\text{Ksho} = \frac{1}{3{,}96} = 0{,}253.$$

Since the estimated Ksho. = 0,249 is greater than 0.16, the part is considered normal in the complexity of its manufacture.

2. The level of manufacturability in terms of precision machining.

The accuracy factor K_{then} is a relative indicator of manufacturability and is determined according to GOST 14202-73.

Calculation formula:

$$K_{T.O.} = 1 - \frac{1}{A_{CP.}}$$

de A$_{CP}$. - average quality of accuracy of processing of a detail;

$$A_{CP.} = \frac{6n_6 + 7n_7 + 8n_8 + ... + 17n_{17}}{n_6 + n_7 + n_8 + ... + n_{17}}$$

where 6 -17 - quality of manufacturing accuracy;

n6 - n17 - the number of sizes of this quality;

$$\text{A}_{\text{CP.}} = \frac{17\cdot 48 + 15\cdot 1 + 14\cdot 3 + 13\cdot 3 + 8\cdot 5 + 7\cdot 2}{48 + 1 + 3 + 3 + 5 + 2} = 15{,}09$$

$$K_{T.O.} = 1 - \frac{1}{15{,}09} = 0{,}929$$

Since K_{then}= 0.929> 0.85 then the part is considered of normal accuracy.

Based on qualitative and quantitative assessment of manufacturability we have established that the part is sufficiently technological and thus we do not need to change the flange drawing 753.172.004.

1.3 Analysis of the basic technological process

The analysis of the existing technological process of manufacturing the part is carried out in order to identify shortcomings in the basic technological process, as well as the degree of its compliance with the projected process [14]. The actual technological process and the means of its machine and technological equipment are subject to analysis.

Table 1.2 - Factory part processing route

Operation	The name of the operation	Equipment	The content of the operation	Tsht (min.)
1	2	3	4	5
005	Turning	Semi-automatic lathe model 1734	Processing of base surfaces (the largest diameter) on which the detail will be based on 010, 015 operations, and rough trimming of an end face	2.25
010	Turning	Semi-automatic lathe model 1734	Rough trimming of the end face on the other side	2.43
020	Aggregate	special drilling model AM-7787	The big end is processed first: drilling of 4 openings in which the M8-7H cut is cut, the countersink roughing of "central" opening under the Ø71 bearing is carried out, and 5 openings Ø18 + 0,035 are drilled, countersunk, developed.	2.35
030	Aggregate	special drilling model AM-7787	4 holes in which the M8-7H cut is cut are drilled, and the countersink is roughing of "central" opening under the Ø61 bearing.	2.40

Continuation of table 1.2

1	2	3	4	5
040	Diamond-boring	Special-boring models OS-4555	Two holes for bearings are drilled simultaneously	2.42
050	Turning	Turning multicutter semiautomatic device of the 1H713 model	Simultaneous finishing trimming of the largest diameter on two sides	1.92
060	Locksmith-on	Workbench №1910	Blunt sharp edges	1.15
070	Flush-eye	My washing machine LP1320	Washing and drying	0.069
085	Control flax	Table of technical control department	Carry out control	1.12
TOGETHER:				15.58

The basic technological process of mechanical processing of the flange 753.172.004 is developed for the conditions of large-scale current production and is characterized by the use of a large number of metal-cutting equipment.

Directions improve the basic technological process is the use of CNC machines equipped with two coaxial spindles.

1.4 Conclusions and tasks for qualification work

As a result of the analysis of the design, manufacturability and basic technological processing of the part "Flange753.172.004", it can be concluded that in general the part is technological, does not cause much difficulty in the manufacture, the material and design of the parts are sufficiently worked out for manufacturability.

When performing work, it is necessary to improve the existing technological process in order to improve it in accordance with the proposed measures, that is, to develop an optimal technological process of machining, in which the shortcomings identified in the basic technological process should be eliminated , to choose modern technological equipment and necessary equipment, to choose a more rational way to obtain the workpiece, to calculate the allowances for processing, cutting modes and time standards for operations. It is necessary to select effective technological equipment, equipment and the necessary cutting tool for the operations of the developed technological process, as well as the choice of device for machining, to calculate the error of installing the part in the proposed device, as well as the calculation and choice of the device drive.

In addition, it is necessary to consider the safety of life and the basics of labor protection in case of emergencies at the enterprise.

2 TECHNOLOGICAL PART

2.1 Determining the type of production

The type of production in mechanical engineering determines the various methods and techniques of manufacturing parts and components of machines. According to GOST 3.1108-74 there are such as single, small series, medium series, large series and mass production types.

To pre-determine the type of production we use data from the factory on the part "Flange": Annual program of production of details: Np = 2900 pieces; Weight of a detail: 6,15 kg; The mode of operation of the enterprise: two-shift;
Actual annual equipment operating time fund: $F_{д} = 3890$ hours. (for CNC machines).

Preliminarily, we focus on the choice of type of production [2] for parts weighing up to 10 kg. and a given volume of production N = 2900 pieces - the recommended type of production corresponds to the average series.

2.2 Choosing the method of obtaining the workpiece

According to the basic technological process, the method of obtaining the workpiece is casting in sand-clay molds.

Casting is proposed as a new way to obtain the workpiece in the chill mold and casting on fired models [8].

Molds (molds) for the manufacture of blanks are completely metal or combined with the use of non-metallic cones. The main advantages of this method of making castings: the possibility of multiple use of the mold; high accuracy of the form and the sizes, a qualitative surface of preparation; fine-grained structure of the material; relatively high productivity; low complexity and cost of blanks; no need for model, support equipment and molding mixtures; good working conditions; efficiency in serial production; does not require highly skilled workers; relatively smaller production areas are required; no operation of cleaning castings from the mixture, the pouring system; suitability for mechanization and automation.

Molds allow to receive castings with the exact sizes of surfaces (12th quality) and their roughness to 5 microns for the parameter Ra.

Casting is offered as the second variant of receiving preparation according to the burned models.

Casting according to the fired models it is possible to make blanks weighing from 0.03 to 100 kg with a minimum wall thickness of 0.6 mm and holes with a diameter of up to 5 mm.

The advantages of this method of making castings - high accuracy of shape and size, surface quality of workpieces, low casting inclinations, absence of cones, small allowances for processing by cutting, besides castings easily separate from the form, do not burn, the form has no plane of socket and sign parts that provides the increased accuracy of castings.

This method of obtaining the workpiece allows you to make castings from dimensional accuracy (up to 11th quality) and mutual placement of surfaces and their roughness up to Ra 2… 4 with minimal allowances for cutting.

Therefore, in this case we accept the following methods of obtaining the workpiece:

Option 1 - molding;

Option 2 - casting on fired models.

For the first variant of receiving preparation (molding in a chill mold) we establish:

1) manufacturing accuracy class - 5th;
2) accuracy class of sizes, weights and series of allowances - 2nd.

For the second option of obtaining the workpiece (casting according to the burned models) we establish:

1) manufacturing accuracy class - 4th;
2) accuracy class of sizes, weights and series of allowances - 2nd.

We choose from [26, 27] allowances and tolerances of blanks and enter them in table 2.1.

Table 2.1 - Allowances and tolerances on the design blanks

Size	Type of workpiece			
	Die casting		Casting on smelted models	
	Tolerance	Allowance	Tolerance	Allowance
80	0,44	0,8 – 1,0	0,70	1,0 – 1,4
62	0,40	0,8 – 1,0	0,64	1,0 – 1,4
54	0,40	0,8 – 1,0	0,64	1,0 – 1,4
63	0,40	0,8 – 1,0	0,64	1,0 – 1,4
72	0,44	0,8 – 1,0	0,70	1,0 – 1,4
210	0,56	0,9 – 1,2	0,90	1,0 – 1,4
20	0,32	0,7 – 0,9	0,50	0,8 – 1,0
18	0,32	0,7 – 0,9	0,50	0,8 – 1,0

We determine the weight of the workpiece $M_{\text{заг.к.}}$ in each of the proposed options based on their 3D models [9-13]:

For molding

$$M_{\text{заг.к.}} = 6,6 \text{ kg};$$

For casting on smelted models:

$$M_{\text{заг.вип.м.}} = 7 \text{kg}.$$

Based on this, we will determine the utilization factors of the material for different methods of obtaining the workpiece:

For molding

$$К_{ВМ1} = \frac{6,1}{6,6} \cdot 100\% = 92\%;$$

For casting in molds with molten models:

$$К_{ВМ1} = \frac{6,1}{7} \cdot 100\% = 87\%.$$

We will determine the cost of manufacturing one blank by the formula [5]

$$S_{gen} = \left(\frac{C_i}{1000} \cdot Q \cdot k_{\text{т}} \cdot k_{\text{с}} \cdot k_{\text{в}} \cdot k_{\text{м}} \cdot k_{\text{п}} \right) - (Q - q) \frac{S_{\text{відх.}}}{1000} ,,$$

We choose according to the sitehttp://www.infoprofil.ru indicator of the cost of one ton of blanks C_i and the cost of one ton of waste $S_{\text{відх.}}$. We choose the mass of the workpiece Q from previous calculations.

We choose the values of the coefficients $k_т, k_с, k_в, k_м, k_п$ according to the recommendations [2] for each method of obtaining the workpiece.

For molding:

$$S_{gen}^{1} = \left(\frac{200}{1000} \cdot\ 6{,}6 \cdot\ 1{,}64 \cdot\ 1{,}42 \cdot\ 1{,}06 \cdot\ 1{,}0 \cdot\ 1{,}0\right) - (6{,}6 - 6{,}1) \cdot \frac{80}{1000};$$

$$S_{gen}^{1} = 3{,}22\ \mathrm{U}SD$$

For casting by smelted models:

$$S_{gen}^{2} = \left(\frac{222}{1000} \cdot\ 7 \cdot\ 1{,}64 \cdot\ 1{,}42 \cdot\ 1{,}06 \cdot\ 1{,}0 \cdot\ 1{,}0\right) - (7 - 6{,}1) \cdot \frac{80}{1000};$$

$$S_{gen}^{2} = 3{,}76\ \ \mathrm{U}SD$$

Die casting is a better option because of the higher utilization rate of the material and lower cost of the workpiece compared to casting on smelted models.

2.3 Choosing technological bases

We can use the base surfaces G, F, C, I, P, A to treat surfaces B1, B, Z, M, D, K, E. The error in basing on P and A will be minimal. To treat surfaces A, O, G, H, C, I, S, as bases, we can use surfaces D, E, B1, B, Z. When basing on surfaces B and C, the installation error will be minimal. For the base surfaces, we can choose G, C, I, F, P, O, A for machining holes with threads M8-7H and holes Ø18 + 0.035. We will be able to ensure the parallelism of the axes of the machined holes of the axis of the part based on A and O. We can also choose the base surfaces B, B, Z, A, O, P, D, E, L for drilling and subsequent cutting in the holes M8-7H. We will achieve the smallest error of basing on placement of the given apertures on the processed apertures L and an end face B. For final processing of surfaces under bearings C, D and accordingly their end faces I and K,

We offer such part basing schemes to ensure high machining accuracy.

1. We base on the untreated surface with an emphasis on the end of the largest diameter.
2. We carry out base on the processed surface, the largest diameter with an emphasis in the end face.
3. We base the part in the xz plane at the end. The angular position of the "ears" of the flange on the y-axis is fixed by a folding bar. We fix the part by diameter∅141.
4. We base on two mounting pins. This allows you to accurately set the part relative to the axis and threaded alignments from the opposite end of the part.
5. We base on two mounting pins. This allows the part to be set with sufficient accuracy relative to the common axis and prevents the part from scrolling during machining.

2.4 Designing a technological route of mechanical processing details

When choosing a processing route, we are guided by the following considerations:

We can use processing methods: milling, turning, grinding to process surfaces A, B1, B, G, which are the end surfaces of the body of rotation. The use of grinding operations is impractical, given the requirements for roughness and accuracy of processing of these surfaces. Milling is difficult due to the stepwise arrangement of the ends and the formation of the surface O, when processing the surface A, which is cylindrical. The best method of processing is turning. This will make it possible to process for one institution the surface B1, B, K, M, and for the other - the end G and the chamfer N.

Surfaces C, I, E, D, are internal and geometrically cylindrical. We can process them in such ways as: boring, countersinking, turning and grinding. We must introduce into the process route additional operations and equipment for countersinking, reaming and grinding. The use of boring as a rough finish will allow you to perform machining on the same operations as turning the ends. We can use grinding or diamond boring, given the roughness of surfaces C and D for finishing. Diamond boring is more appropriate because of its higher performance and accuracy.

For processing of openingsØ18 + 0.035 we can use drilling, countersinking, reaming. It is advisable to use all three methods, taking into account the technical requirements for the surfaces of the holes. The only processing methods are drilling and subsequent cutting of the thread to form threaded holes at the ends.

Table 2.2 - The optimal processing route of the part

№ p.p.	The name of the operation	Treated surfaces	Surfaces that serve as bases	Equipment (machine)
1.	Semiautomatic turning Position I	A, B, E, D, К, M	A, P	Turning machining center
	Position II	A, G, H, C, I	B, Z	
2.	Special aggregate	L, T	A, O, R	Special AG1
3.	Special aggregate	Y	A, B, L	Special AG2
4.	Diamond-boring	C, I, D, К	A, B1, L	Diamond boring

2.5 Determination of allowances for processing

Calculation of allowances by calculation and analytical method for processing the flange hole. $Ø72P7_{-0,051}^{-0,021}$

Characteristics of the workpiece: casting of the second accuracy class weighing 7.3 kg .; technological route of processing of an aperture consists of rough, finishing and diamond boring.$Ø72P7_{-0,051}^{-0,021}$.

We enter in table 2.5 all calculations of allowances and limit sizes on technological transitions. We choose from table 27 [3] the total value of Rz and T, which characterizes the surface of the cast billet Rz = 200, T = 300.

For the first technologicaltransition value T for parts made of cast iron is zero. We find only the values of Rz, respectively 50, 20 and 8 micron [1, 2] for all other transitions.

We calculate the minimum values between operating allowances by the formula:

$$2Z_{min} = 2(R_{zi-1} + T_{i-1} + \sqrt{\rho_{i-1}^{2} + \mathcal{E}_{i}^{2}}\ .$$

Table 2.3 - Calculation of allowances and limit sizes for technological transitions to the processing of the flange hole Ø72P7$^{-0,021}_{-0,051}$

Technological transition	Allowance elements, µm				Calculated Allowance 2zmin, µm	Tolerance δ, µm	Maximum size, mm		Marginal allowance, µm	
	Rz	T	ρ	ε			dmin	dmax	$2z^{пр}_{min}$	$2z^{пр}_{max}$
The workpiece	200	300	11,7	-	-	400	69.8	70.20	-	-
Rough boring the hole	50	-	0,59	300	2*800	170	71.63	71,796th most common	1600	1830
Finish boring the hole	20	-	-	15	2*65	50	71,876 th most common	71.930	130	249
Diamond boring the hole	8	-	-	6.6	2*26,6	30	71,949 th most common	71.980	54	73
Total									1779	2149

Table 2.4 - Calculation of allowances and limit sizes

1	The total value of spatial deviations for the workpiece	$\rho_з = \sqrt{\rho_{кор}^2 + \rho_{см}^2}.$
2	The magnitude of the warping of the hole	$\rho_{кор} = \sqrt{(\Delta_к d)^2 + (\Delta_к l)^2}$; (d and l - diameter and length of the processed hole): $\Delta_к = 0{,}7\ micron$ $\rho_{кор} = \sqrt{(0{,}7 \cdot 72)^2 + (0{,}7 \cdot 27{,}5)^2} = 7{,}9\ micron.$
3	The total displacement of the hole in the casting relative to the outer surface	$\rho_{кор} = \sqrt{\left(\frac{\delta_б}{2}\right)^2 + \left(\frac{\delta_б}{2}\right)^2} = \sqrt{\left(\frac{400}{2}\right)^2 + \left(\frac{400}{2}\right)^2} = 284\ micron,$ $\delta б = \delta г = 0{,}4$mm (Table 7)
4	The total value of the spatial deviation of the workpiece	$\rho_з = \sqrt{284^2 + 7{,}5^2} = 11{,}7\ mkm$
5	The magnitude of the residual spatial deviation after rough boring:	$\rho_1 = 0{,}05\rho_з = 0{,}05 \cdot 11{,}7 = 0{,}59\ micron$
6	Installation error during rough boring [26]:	$\mathcal{E}1 = 300$ micron.
7	Residual error in pure boring	$\mathcal{E}_2 = 0{,}05 \cdot \mathcal{E}_1 = 15\ micron.$
8	Error in diamond boring	$\mathcal{E}_3 = 0{,}022 \cdot \mathcal{E}_1 = 6{,}7\ micron.$
9	Rough boring:	$2Z_{min} = 2\left(200 + 300 + \sqrt{11{,}7^2 + 300^2}\right)$ =2800 micron ·

10	Finish boring	$2Z_{min} = 2\left(50 + \sqrt{0,59^2 + 15^2}\right)$ $= 2 \cdot 65\, micron$
11	Diamond boring	$2Z_{min} = 2\left(20 + \sqrt{6,6^2}\right) = 2 \cdot 26,6\, mkm$

12	Estimated size	dp1 = 71.979 mm - from the drawing;
		dp2 = 71.979 - 0.0532 = 71.93 mm;
		dp3 = 71.926 - 0.130 = 71.8 mm;
		dp3 = 71.796 - 1.600 = 71.2 mm.

13	The smallest size limit	Tolerance values for diamond boring 30 micron; for finishing
		$\delta = 50$ µm; for rough $\delta = 170$ mkm; for casting according to GOST 1855 $\delta = 400$ mkm.
		dmin1 = 71.98 - 0.030 = 71.95 mm;
		dmin2 = 71.93 - 0.050 = 71.846 mm;
		dmin3 = 71.8 - 0.170 = 71.63 mm;
		dmin c = 71.2 - 0.400 = 69.8 mm.

14	Minimum and maximum limit allowances for	
15	Diamond boring:	$2Z_{min3}^{пр} = 71,979 - 71,926 = 0,054\, mm;$ $2Z_{max3}^{пр} = 71,949 - 71,876 = 0,073\, mm.$
16	Finish boring:	$2Z_{min2}^{пр} = 71,926 - 71,796 = 0,130\, mm;$ $2Z_{max2}^{пр} = 71,875 - 71,686 = 0,249\, mm.$
17	rough boring:	$2Z_{min1}^{пр} = 71,796 - 70,196 = 1,600\, mm;$ $2Z_{max1}^{пр} = 71,626 - 69.796 = 1,830\, mm.$
18	General allowances:	$2Z_{min} = 54 + 130 + 1600 = 1784\, mkm$ $= 1,784\, mm;$ $2Z_{max} = 73 + 249 + 1830 = 2152\, mkm$ $= 2,152\, mm.$
19	General nominal allowance	$2Z_{ном} = 1784 + 200 - 30 = 1954\, mkm$ $= 1,954\, mm.$ $dз_{ном} = d_{ном} - Z_{ном} = 72 - 1,954 = 70,046\, mm$

We choose the allowances and tolerances for the remaining machined flange surfaces according to the tables according to GOST 26645-85 and we enter their values in table 2.5

Table 2.5 - Allowances and tolerances on the machined flange surfaces

Name operations	Estimated values			The resulting size
	Allowance tabular, mm	Allowance calculated, mm	Tolerance, mm	
1. Size Ø72P7				
a) Diamond boring	0.45	0,044	P7	Ø 72P7
b) Finish boring	1,0	0.120	+0.074	Ø72.60 $_{+0.074}$
c) Rough boring	2,10	1.90	+0.190	Ø 70.6 $_{+0.19}$
d) Workpiece			± 1	Ø 68.6 ± 1
2. Size Ø64H14				
a) Rough boring	3,0	-	H14	Ø 64H14
b) Workpiece			± 1	Ø 62 ±1,0
3. Size Ø63 + 0.074			+0,074	
a) Rough turning	3,0	-	± 1	Ø 63 $_{+0.740}$
b) Workpiece				Ø 61 $_{\pm 1,0}$
4. Size Ø82P7				
a) Diamond boring	0.50	-	P7	Ø 82P7
b) Finish boring	1,02	-	+0,072	Ø82.6 $_{+0.074}$
c) Rough boring	3,0	-	+0.19	Ø 80.6 $_{+0.19}$
d) Workpiece			± 1	Ø 78.6 $_{\pm 1}$
5. Size Ø141 (IT13 / 2)				
a) Rough turning	2.60	-	IT13/2± 1	Ø141$\frac{IT13}{2}$
b) Workpiece				143.5 $_{\pm 1,0}$
6. Size Ø220x14				
a) Rough turning	2.50	-	h14	Ø 220x14
b) The workpiece			±1,2	Ø222,8±1,2
7. Size 90x13				
a) face finishing	1 + 1.4 =	-	h13	90 x13
b) Rough turning of butt	2.40	-	-0.230	92.3-0.23
c) Workpiece	1,5+1,5=3		±1	96,1±1,0
8. Size 20x14				
a) Rough turning of butt	1.6 + 1.60 =	-	h14	20 x14
b) Workpiece	3.20		±0,6	23±0,60
9. Size 12				
a) Rough turning of butt	1.50	-	h14	12 x14
b) Workpiece			±0,5	12,5±0,50

Foundry slopes do not exceed 1°; radii of rounding 2 ÷ 6 mm [3].

We perform drawings of the workpiece according to these data.

2.6 Dimensional analysis of the technological process

As is known, the dimensional connection of parts is established by dimensional chains according to GOST 16319 - 80. According to this GOST the dimensional chain is a set of the sizes forming a closed contour and characterizing the given design. Any dimensional chain consists of one locking link and two or more components that affect the accuracy of the locking link.

So, we must determine the size of the closing link according to the known tolerance of the links of this dimensional chain.

For this we make the scheme of a dimensional chain (fig. 2.1).

So, we have from the figure: $A_1 = 3 \pm 2;\ A_2 = 80_{-0,46};\ A_3 = 20_{-0,52}$

We must determine with what accuracy the length will be sustained to a greater extent with a given processing scheme.

Next, we build a diagram of the dimensional chain, identify the closing, increasing and decreasing links.

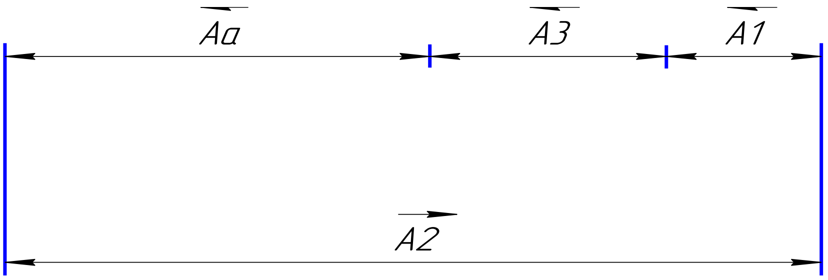

Figure 2.1 - Dimensional chain

The largest value of the closing link is determined by the formula:

$$A\delta = A_2 - A_3 - A_1 = 80 - 3 - 20 = 57\ mm.$$

We solve the problem of the dimensional chain by the method of maximum - minimum.

We determine the coordinate of the middle of the tolerance field of the closing link:

$$\Delta_{\text{о}\Delta} = (-0{,}23) + 0 + (-0{,}26) = -0{,}49\, mm.$$

We determine from equality the value of the tolerance field of the closing link:

$$\delta_{\Delta} = 0{,}46 + 0{,}52 + 0{,}4 = 1{,}38\, mm.$$

Then we find the limiting deviations of the closing link:

$$\Delta_{\text{в}\Delta} = \Delta_{\text{о}\Delta} + \frac{\delta_{\Delta}}{2} = -0{,}49 + \frac{1{,}38}{2} = 0{,}2\, mm;$$
$$\Delta_{\text{н}\Delta} = \Delta_{\text{о}\Delta} - \frac{\delta_{\Delta}}{2} = -0{,}49 - \frac{1{,}38}{2} = -1{,}18\, mm.$$

So, in the end we get: $\mathrm{A}_{\delta} = 57^{+0{,}20}_{-1{,}18}$.

We determine by a tabular method for the sizes which tolerance fields are not specified in the drawing on 14 quality for surfaces which are subject to processing and on 16 quality which are not processed. We summarize in Table 2.6 the obtained values.

Table 2.6 - Flange size tolerance fields

Link	Size links, mm	Field tolerance, mm	Upper deviation	Lower Deviation	Terminal size, mm
A_1	3	0,4	+0,2	-0,2	3±0,2
A_2	80	0,54	0	-0,46	$80_{-0,46}$
A_3	20	0,48	0	-0,52	$20_{-0,52}$
A_4	57	1,2	+0,2	-1,18	$57^{+0,20}_{-1,18}$
A_5	62,5	0,7	0	-0,3	$62,5_{-0,3}$
A_6	Ø131	0,63	+0,315	-0,315	Ø131±0,315
A_7	Ø114,1	2,2	0	-2,2	$Ø114,1_{-2,2}$
A_8	Ø62	0,03	-0,021	-0,051	$Ø72^{-0,021}_{-0,051}$
A_9	Ø54	0,74	+0,74	0	$Ø54^{+0,74}$
A_{10}	8	4	+2	-2	8±2
A_{11}	Ø90	2,2	0	-2,2	$Ø90_{-2,2}$
A_{12}	Ø63	0,74	+0,74	0	$Ø63^{+0,74}$
A_{13}	27	0,33	+0,33	0	$27^{+0,33}$
A_{14}	Ø72	0,03	-0,021	-0,051	$Ø72^{-0,021}_{-0,051}$
A_{15}	Ø95	0,46	0	-0,54	$Ø95_{-0,54}$
A_{16}	Ø150,8	0,37	0	-0,63	$Ø150,8_{-0,63}$
A_{17}	18	1,8	+1,8	0	$18^{+1,8}$
A_{18}	36	1,6	0	-1,6	$36_{-1,6}$
A_{19}	10	0,78	0	-0,22	$10_{-0,22}$

2.7 Choice of cutting and measuring tool

We select cutting and measuring tools based on the recommendations of scientific and technical literature and company brochures (Table 2.7).

Table 2.7 - Cutting and measuring tools

Operation	Cutting tool	Measuring tool
CNC lathe	Mandrel C5-SCLC R - 35060-09. Cutter checkpoint Mvjnr 2525 M16 Dimensions: Length-150mm. Section - 25x25mm. Departure - 42mm; Cutter through passage direct PCLNR 3225p12 Dimensions: Length-170mm. Section - 32x25mm. Departure - 32mm; The through cutter is bent right Mvjnr 2525 M16. Dimensions: Length-150mm. Section - 25x25mm. Departure - 42mm; Cutter boring S25T-SCLCR 12 Dimensions: Length-300mm. Cross section - ø25mm. Departure from the axis - 17mm; Cutter boring S16R-SCLCR 09 Dimensions: Length-200mm. Cross section - ø 16mm. Departure from the axis - 11mm; Cutter through passage Pclnr 3232 p19 Dimensions: Length-170mm. Section - 32x32mm. Departure - 40mm; Cutter boring S16R-SCLCR 09 Dimensions: Length-200mm. Cross section - ø 16mm. Departure from the axis - 11mm	Bracket 220h12 special; Plug 82H9 (+0.072) GOST 14823-69; The template is special; Plug 54H14 (+0.74) special; Bracket 82h13 special; Stopper 72H9 (+0.074) GOST 14823-69

End of table 2.7

Operation	Cutting tool	Measuring tool
Aggregate	Drill 803D6,8-90-S32 Dimensions: Length - 185mm. Diameter - Ø6.8 mm Countersink (Ø17,7) VK8 GOST 12489-71; Drill 803D16-90-S32 Dimensions: Length - 185mm. Diameter - Ø6.8 mm; Scan VK6 (Ø18H9) GOST 1672-80; Countersink P6M5 GOST 21582-76; Tap M8 P6M5 GOST 29221-91	Stopper Ø18 + 0,035 special; The caliber is special for placing the heel holes Ø18 + 0.035; Threaded plug M8-H7 GOST 17758-72
Aggregate	Drill 803D6,8-90-S32 Dimensions: Length - 185mm. Diameter - Ø6.8 mm; Countersink P6M5 GOST 21582-76; Tap M8 P6M5 GOST 29221-91	Caliber thread special; Threaded plug M8-H7 GOST 17758-72
Diamond-boring	Drilling rod; Cutter boring for blind holes S25T-SCLCR 12. Dimensions: Length-300mm. Cross section - ø25mm. Departure from the axis - 17mm;	The stopper is special;$Ø72P7_{-0,051}^{-0,021}$ Bracket 72.5-0.3 special; The template is special; The stopper is special $Ø72P7_{-0,051}^{-0,021}$

2.8 Calculation and selection of processing modes

As you know, we can determine the cutting modes by two methods: tabular and analytical calculation.

We perform analytical calculations for one transition of turning operation (turning of ends A and G) on the M40-G machine and one transition of aggregate operation (simultaneous drilling of four holes Ø6,8 mm) on the AG1 machine.

Analytical calculationcutting modes for turning the ends A and G are as follows.

We calculate for the transition of turning the surface A, because we plan to process two tools simultaneously, and the modes will be limiting when turning the end face A (depth of cut is the same, and the speed and length of the treated surface prevails when processing the end face A).

Cutting tool - cutter bent right Mvjnr 2525 M16.

We assign a cutting depth equal to the allowance for the treatment of this surface: t = 1.5 mm because the requirements for the roughness of this surface (Ra = 6.3mkm) can be met in one pass.

We calculate the supply by the analytical method according to the formula:

$$S = \sqrt[Ypz]{\frac{3EIf}{1,1L^3 Cpz\, t^{Xpz}}},$$

where E is $1.6*10^5$ MPa;·

I - the moment of inertia of the cross section of the part:

$$I = \frac{\pi d_з^4}{64}(1-(\frac{d_в}{d_з})^4) = \frac{3,14 \cdot 210^4}{64} \cdot (1-\left(\frac{72}{210})^4\right) = 941 \cdot 10^5\ mm^4;$$

f - allowable bending of the part (f = 0.30);

L is the length of the part (f = 80 mm);

C_{pz} - coefficient of material, C_{pz} = 92;

Y_{pz} = 0.75; X_{pz} = 1,0.

$$S = \sqrt[0,75]{\frac{3 \cdot 1,6 \cdot 10^5 \cdot 941 \cdot 10^5 \cdot 0,3}{1,1 \cdot 80^3 \cdot 92 \cdot 1,5^1}} = 0,42 \frac{mm}{rev}.$$

Period of stability of the cutter: T = 60 minutes

Cutting speed:

$$v = \frac{C_v}{T^m t^{x_v} S^{y_v}} K_v.$$

Where $C_v = 243;\ x_v = 0{,}15;\ y_v = 0{,}4;\ m = 0{,}2;\ K_v = K_{mv}, K_{nv} = 0{,}85;\ K_{uv} = 0{,}83,$ $K_{nv} = 0{,}85;\ K_{uv} = 0{,}83,$ then Kv = 1,250*0,850*0,830 = 0,880.··

$$v = \frac{243}{60^{0,2} \cdot 1{,}5^{0,15} \cdot 0{,}42^{0,4}} 0{,}88 = 126{,}7 \frac{m}{min}.$$

Spindle speed:

$$n = \frac{1000v}{\pi d} = \frac{1000 \cdot 126{,}7}{3{,}14 \cdot 210} = 192 \frac{rev}{min}.$$

Cutting power:

$$N_{\text{різ}} = \frac{P_z v}{60 \cdot 102}.$$

Cutting force:

$$P_z = C_{pz} t^{x_{pz}} S^{y_{pz}} v^{n_{pz}} K_{pz}.$$

Where $C_p = 92;\ x_p = 1;\ y_p = 0{,}75;\ n_p = 0{,}15;$ then $K_p = K_{\text{мп}} K_{\varphi\text{п}} K_{yp} K_{\lambda p} K_{rp}, K_{\text{мп}} = 1;\ K_{\varphi\text{п}} = 1;\ K_{yp} = 1{,}1;\ K_{\lambda p} = 1; K_{rp} = 0{,}93, K_p = 1 \cdot 1 \cdot 1{,}1 \cdot 1 \cdot 0{,}93 = 1{,}023.$

$$P_z = 92 \cdot 1{,}5^1 \cdot 0{,}42^{0,75} \cdot 126{,}7^0 \cdot 1{,}023 = 73{,}6\ \text{Н}.$$

$N_{\text{різ}} = \frac{73{,}6 \cdot 126{,}7}{60 \cdot 102} = 1{,}52\ \text{кВт};\ N_{\text{різ.п.}} = 2N_{\text{різ}} = 1{,}52 \cdot 2 \approx 3\ \text{кВт}.$

Main time:

$$T_o = \frac{L_i}{nS},$$

$where\ \ L_i = \frac{d_з - d_в}{2} = \frac{210 - 131}{2} = 39{,}5\ mm;\ n = 192\ \frac{rev}{min};\ \ S = 0{,}42\ \frac{mm}{rev}, then:$

$$T_o = \frac{39{,}5}{192 \cdot 0{,}42} = 0{,}49\ min.$$

Analytical calculation of cutting modes for simultaneous drilling of four holes Ø6.8 mm

Cutting tool - drill803D6,8-90-S32. The material of the cutting part of the drill is high-speed steel.

Cutting depth:

$$t = 0{,}5D,$$

where D is the diameter of the drill D = 6.8 mm;

$$t = 0{,}5 \cdot 6{,}8 = 3{,}4\; mm.$$

Tool feed [9]:

$$s = 0{,}24\frac{mm}{rev}.$$

Cutting speed when drilling:

$$v = \frac{C_v D^q}{T^m S_o^y} K_v K_{3v},$$

where the correction factor for the cutting speed during drilling;$C_v -$

$q, m, y -$indicators of degrees;

$T -$ the period of stability of the tool;

$K_v -$total correction factor, taking into account the cutting conditions (processed material $K_{\text{м}v}$; drilling depth K_{lv}, tool material K_{uv}):

$$K_v = K_{\text{м}v} K_{uv} K_{lv},$$

where the correction factor for sharpening the drill, $K_{3v} - K_v = 0{,}75$;

S_v = 14.70; q = 0.245; y = 0.545; m = 0.1245; T = 60 min.

$$K_{\text{м}v} = \left(\frac{190}{HB}\right)^{n_v},$$

where $n_v = 1{,}3$;

$$K_{\text{м}v} = \left(\frac{190}{190}\right)^{1{,}3} = 1;$$

$K_{uv} = 1$;then$K_{lv} = 1, K_v = 1 \cdot 1 \cdot 1 = 1.$

$$v = \frac{14{,}7 \cdot 6{,}8^{0{,}25}}{60^{0{,}125} \cdot 0{,}24^{0{,}55}} \cdot 1 \cdot 0{,}75 = 23\frac{m}{min}.$$

We assume a cutting speed of 9.8 m/min to ensure a given tool life, taking into account the recommendations [4] for the cutting speed when drilling.

Spindle speed:

$$n = \frac{1000v}{\pi D} = \frac{1000 \cdot 9{,}8}{3{,}14 \cdot 6{,}8} = 460\frac{rev}{min}.$$

Minute feed:

$$S_{\text{хв}} = n \cdot S_o = 460 \cdot 0{,}24 = 110\frac{mm}{min}.$$

Main timeprocessing:

$$T_o = \frac{L_{\text{р.х.}}}{S_{\text{хв}}},$$

where the length of the stroke of the caliper:$L_{\text{р.х.}} -$

$$L_{\text{р.х.}} = l + l_1,$$

where the cutting length,$l - l = 18\,mm$;

l_1 −cut length:

$$l_1 = t \cdot ctg\varphi + (1 \div 3),$$

where $\varphi -$ the main angle of the tool in the plan;

$l_1 = 3{,}4 \cdot ctg30 + 1 = 6{,}9\,mm$; $L_{\text{р.х.}} = 18 + 6{,}9 = 24{,}9\,mm$;

$$T_o = \frac{24{,}9}{110} = 0{,}23\,min.$$

Torque on the drill [8]:

$$M_{\text{кр}} = 10 \cdot C_{\text{м}} \cdot D^{q} \cdot S^{y} \cdot K_{p},$$

where y = 0.788; , then:$C_{\text{м}} = 0{,}021; q = 1; K_{p} = 1$

$$M_{\text{кр}} = 10 \cdot 0{,}021 \cdot 6{,}8^{1} \cdot 0{,}24^{0{,}8} \cdot 1 = 0{,}45\ Nm.$$

Power of cutting by one tool:

$$N_{p} = \frac{M_{\text{кр}} n}{9750} = \frac{0{,}45 \cdot 460}{9750} = 0{,}021\ kW.$$

Total power:

$$\sum N_{p} = 4 \cdot N_{p} = 4 \cdot 0{,}2 = 0{,}085\ kW$$

We assign a tabular method of cutting modes for the rest of the operations and their transitions. We enter the obtained values in table 2.8.

Table 2.8 - Cutting modes for process operations

Operation and its content	t, mm	S, mm / rev	n, rev / min	v, mm / rev	N_p, kW	To, min.
1	2	3	4	5	6	7
Turning with CNC						
Turning of surfaces Z, D,	1	0.30	160	97.9	0.80	0.96
Turning of end faces B, B1;	2	0.20	160	97.9	2.50	0.78
Turning of surface E,	1	0.08	320	68	0.130	0.48
Turning of a surface B1;	1.40	0.15	320	165	0.9	0.76
Turning of a surface D, chamfers M;	0.6	0.06	850	182	0.140	0.70
Turning of a surface C,	2	0.30	120	22	0.120	0.77
Turning of end faces A, G;	1.60	0.42	180	125	3.10	0.44
Turning of a surface I,	1	0.04	420	69	0.13	0.36
Turning of an end face G;	2	0.20	420	137.6	0.38	0.66
Turning of surface C, chamfers H	0.60	0.05	850	159	0.14	0.45
Aggregate						
Drilling simultaneously 4 holes Ø6,8 (deaf)	3.60	0.25	450	9.9	0.078	0.25
Drilling simultaneously 5 holes Ø16 (per pass)	8	0.25	180	9.50	0.10	0.85
Countersinking simultaneously 5 holes Ø17,7 (per pass)	0.860	0.150	220	12.50	0.05	0.65
Simultaneous rotation of 5 holes Ø18 + 0,035 (per pass)	0.20	1	52	3.50	0.05	0.5

Countersinking chamfer in 4 holes Ø6,8 simultaneously	1.25	1.28	450	12	0.01	0.15
Thread cutting M8-7H simultaneously in 4 holes (length 13mm)	-	1.30	240	5.40	0.04	0.24
Aggregate						
Drilling 4 holes Ø6.8 at the same time (to a depth of 18 $_{+1.8}$)	3.50	0.08	450	9.50	0.08	0.22
Countersinking chamfer in 4 holes Ø6,8 simultaneously	1.25	1.25	460	11	0.012	0.12
Thread cutting M8-7H simultaneously in 4 holes (length 13mm)	-	1.25	240	5.5	0.04	0.24
Diamond-boring						
Boring of a surface of an aperture C,	0.20	0.08	440	86	0.04	0.80
End trimming I;	0.30	0.05	520	118	0.043	1.02
Boring of a surface of an aperture D,						
Trimming of the end face K						

Choice of equipment.

Operation 005 Turning with CNC. Equipment - turning center M40-G (Fig. 2.2).

The machine contains two coaxial spindles. One spindle can move along the center line of the machine. Tool shop for 32 or 54 items.

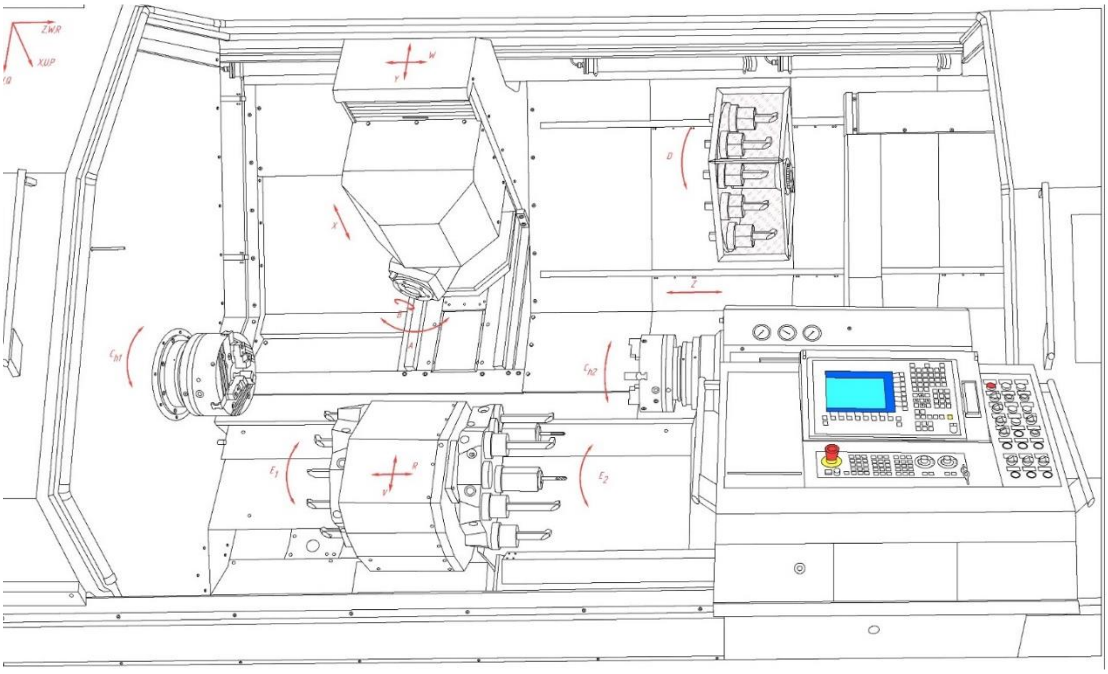

Figure 2.2 - Layout of the M40-G machine

Operation 010 and operation 015. Equipment - special aggregate machines AG1 and AG2.

Operation 020. Equipment - the machine diamond-boring OS 4555 provides processing of details with a diameter of 8 ÷ 250mm. Kinematic characteristics: spindle speed (50 ÷ 2000) rev / min, feed (0.02 ÷ 0.2) mm / rev.

2.9 Calculation and selection of technical standards of time

We perform technical rationing by the analytical method for diamond boring operation, and for the rest of the operations we choose the time norms from tables [6, 18] and summarize them in table 2.9.

We determine the main time of the diamond boring operation.

We take as the main more time: because there is a simultaneous processing of two holes $\text{T}_\text{о} = 1{,}05\, mn.$

Auxiliary time:

$$\text{T}_\text{д} = \text{T}_\text{в.з.} + \text{T}_\text{у} + \text{T}_\text{вим},$$

where the time to install and remove the part;$\text{T}_\text{в.з.} - \text{T}_\text{в.з.} = 0{,}20\, min$

$\text{T}_\text{вим}$ −time to measure the part.$\text{T}_\text{вим} = 0{,}18\, min$

$\text{T}_\text{у}$ −time to control the machine;$\text{T}_\text{у} = 0{,}15\, min$

From here:

$$\text{T}_\text{д} = 0{,}20 + 0{,}15 + 0{,}18 = 0{,}53\text{min}.$$

Operational time:

$$\text{T}_\text{оп} = \text{T}_\text{о} + \text{T}_\text{д} = 1{,}05 + 0{,}53 = 1{,}58\ \text{min}.$$

Workplace maintenance time:

$$\text{T}_\text{тех} = 0{,}04 * \text{T}_\text{оп} = 0{,}04 * 1{,}58 = 0{,}06\, min.$$

Time for organizational maintenance of the workplace:

$$\text{Т}_{\text{орг}} = 0{,}017 * \text{Т}_{\text{оп}} = 0{,}017 * 1{,}58 = 0{,}027\,min.$$

Rest time:

$$\text{Т}_{\text{відп}} = 0{,}05 * \text{Т}_{\text{оп}} = 0{,}05 * 1{,}58 = 0{,}08\,min.$$

Artificial time for operation:

$$\text{Т}_{\text{шт}} = \text{Т}_{\text{о}} + \text{Т}_{\text{д}} + \text{Т}_{\text{тех}} + \text{Т}_{\text{орг}} + \text{Т}_{\text{відп}};$$

$$\text{Т}_{\text{шт}} = 1{,}05 + 0{,}53 + 0{,}06 + 0{,}027 + 0{,}08 = 1{,}75\,min.$$

Preparatory and final time:

$$\text{Т}_{\text{п.з.}} = 25\,min.$$

Artificial calculation time:

$$\text{Т}_{\text{шт.к.}} = \text{Т}_{\text{шт}} + \frac{\text{Т}_{\text{п.з.}}}{N} = 1{,}75 + \frac{25}{500} = 1{,}8\,min.$$

Table 2.9 Calculation of artificial time for process operations

Number and name of the operation	$T_{о}$	Auxiliary time			$T_{оп}$	Service time		Time of resting	$T_{шт}$	$T_{п.з.}$	N, pieces	$T_{шт.}$
		$T_{в.з.}$	$T_{у}$	$T_{вим}$		$T_{тех}$	$T_{орг}$					
005 CNC lathe	0.98	0.23	0.19	0.28	1.65	0.064	0.027	0.083	1.84	22	500	1.88
010 Aggregate	0.72	0.18	0.24	0.40	1.52	0.07	0.024	0.074	1.64	19	500	1.73
015 Aggregate	0.25	0.18	0.24	0.30	0.98	0.05	0.03	0.06	1.05	18	500	1.15
020 Diamond boring	1.08	0.19	0.16	0.19	1.62	0.07	0.028	0.07	1.74	25	500	1.9

2.10 Determination of equipment characteristics. Construction of schedules of loading and use of the equipment

We define the load factor of the equipment as the ratio of the estimated number of machines to the accepted (actual) number of machines:$\eta_з m_р m_п$

$$\eta_з = \frac{m_р}{m_п}.$$

In turn we define the estimated amount of equipment as the ratio of artificial time $Т_{шт}$ per operation to the production rate $t_в$:

$$m_р = \frac{T_{шт}}{t_в}.$$

Therefore, the estimated and accepted amount of equipment is as follows:

Operation 005:$m_р = \frac{1,82}{1,86} = 0,98 m_п = 1$

Operation 010:$m_р = \frac{1,65}{1,86} = 0,89 m_п = 1$

Operation 015:$m_р = \frac{1,08}{1,86} = 0,58 m_п = 1$

Operation 020:$m_р = \frac{1,75}{1,86} = 0,94 m_п = 1$

Then we calculate the load factor of the equipment on operations:

$$\eta_{з\,005} = \frac{0,98}{1} = 0,98; \eta_{з\,010} = \frac{0,89}{1} = 0,89; \eta_{з\,015} = \frac{0,58}{1} = 0,58; \eta_{з\,005} = 0,94.$$

The utilization factor of the equipment on the main (technological) time$\eta_о$is an indicator of the share of machine time in the total operating time of the equipment. We define it as the ratio of basic time to artificial calculation:

$$\eta_о = \frac{T_о}{T_{шт.к.}}.$$

We calculate the figure for each operation:$\eta_о$

$\eta_{\text{o}\ 005} = \frac{0{,}95}{1{,}86} = 0{,}51;\ \eta_{\text{o}\ 010} = \frac{0{,}75}{1{,}69} = 0{,}44;\ \eta_{\text{o}\ 015} = \frac{0{,}23}{1{,}12} = 0{,}2;\ \eta_{\text{o}\ 020} = \frac{1{,}05}{1{,}8} = 0{,}58.$

Then we determine the load factor of the equipment by capacity for the most loaded transition:

$N_{005} = \frac{8{,}07}{22} = 0{,}37;\ N_{010} = \frac{0{,}312}{12} = 0{,}03;\ N_{015} = 0{,}02;\ N_{020} = 0{,}03.$

We build graphs based on the obtained data.

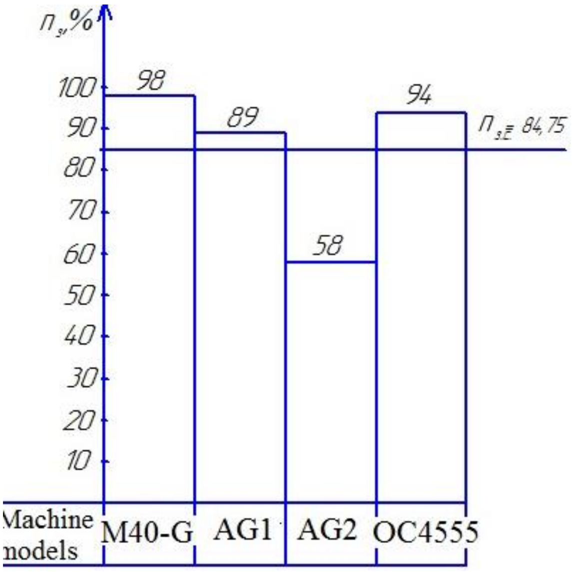

Figure 2.3 Schedule of equipment loading by operations

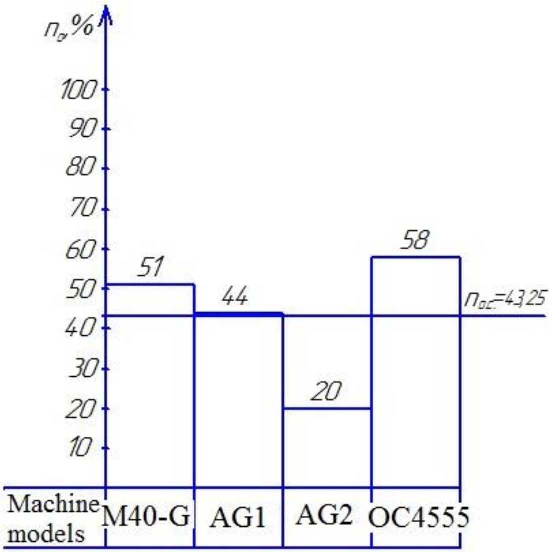

Figure 2.4 Schedule of equipment loading by main time

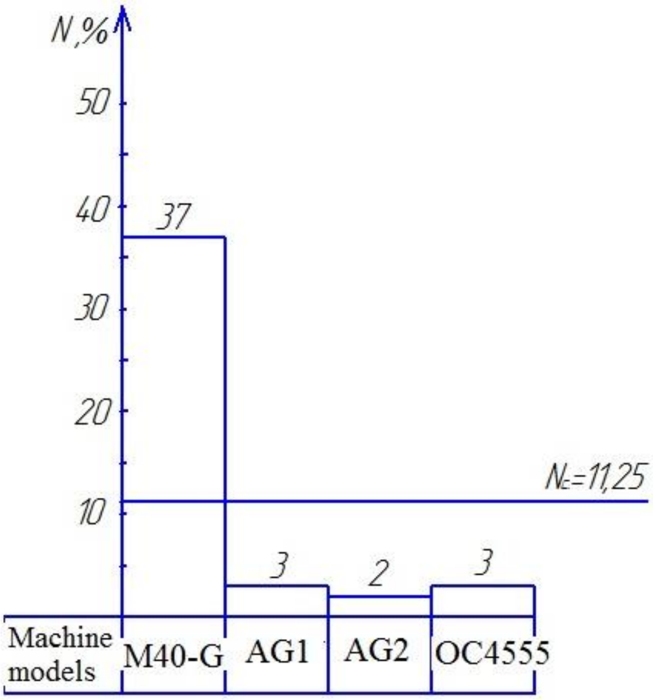

Figure 2.5 Schedule of equipment loading by capacity

3 DESIGN PART

3.1 Calculation of the parameters of the device for drilling four holes Ø6.8 mm

In the designed technological process of manufacturing a flange in the aggregate operation, we use a conductor for drilling four holes. This is a technological device of the stationary type as the part remains stationary during all processing on this AG1 machine. It allows to increase labor productivity and to reduce time of mechanical processing of a detail.

In the device the detail is based on an end surface and on a finger. For this case, the layout of dimensional deviations is shown in the figure. 3.1.

We determine the total deviation:

$$A_{\sum} = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9 + A_{10}$$

where

$A_1 = 0{,}012\,mm$; $A_4 = 0{,}011\,mm$ (H5); $A_7 = 0{,}012\,mm$;

$A_2 = 0{,}012\,mm$; $A_5 = 0{,}012\,mm$; $A_8 = 0{,}011\,mm$;

$A_3 = 0{,}015\,mm$; $A_6 = 0{,}012\,mm$; $A_9 = A_{10} = 0{,}010\,mm$.

So, $$A_{\sum} = 0{,}012 + 0{,}012 + 0{,}012 + 0{,}011 + 0{,}012 + 0{,}012 + \\ + 0{,}012 + 0{,}011 + 0{,}01 + 0{,}01 = 0{,}102\,mm.$$

As is known, the accuracy provided by the device should not be lower than the tolerance for the size from the base to the workpiece surface (0.4 mm).

We have fulfilled the condition A∑ << Δ.

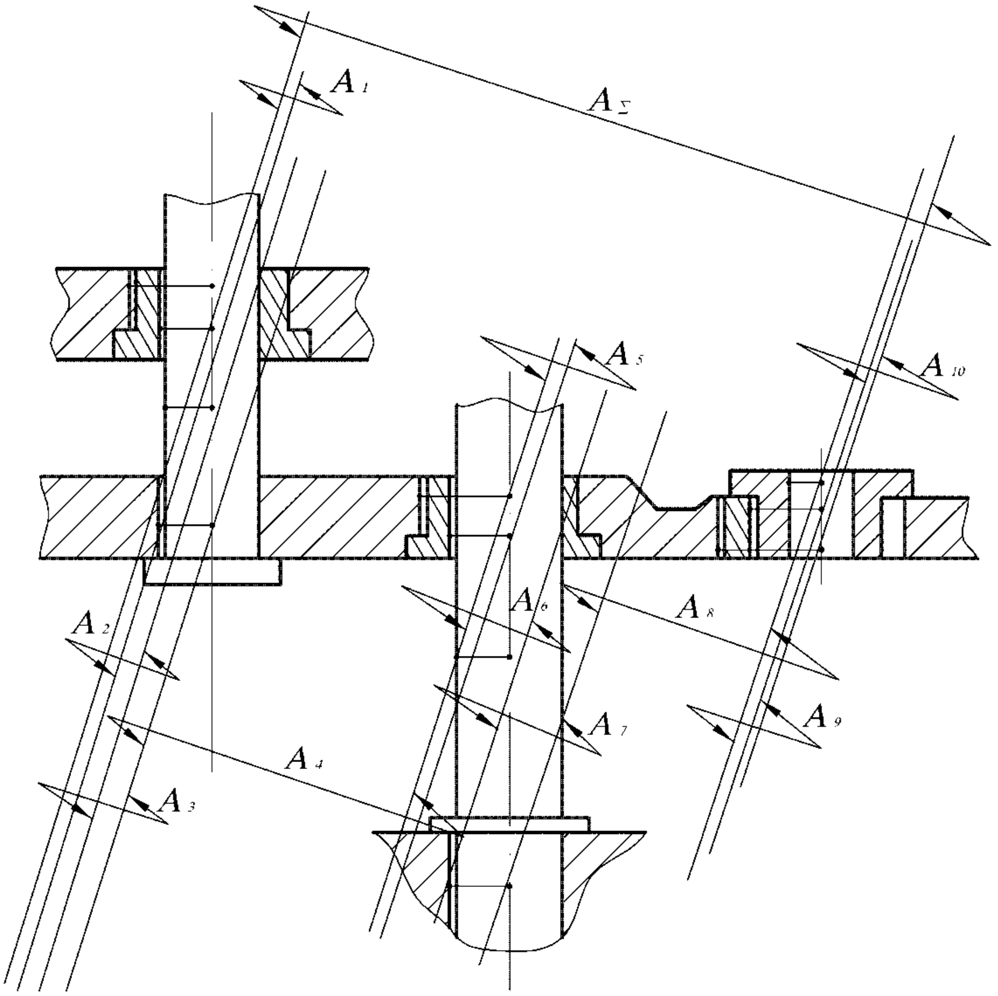

Figure 3.1 - Estimated layout of dimensional deviations

The calculation of the tolerance on the wheelbase of the conductor bushings is as follows.

Tolerance δ_∂ at a distance L_∂ between the axis of the flange hole and the axis of the mounting pin in the conductor is as follows:

$$\delta_{\ddot{a}} = \sqrt{\delta_k^2 + S_1^2 + S_2^2 + E_1^2 + E_2^2},$$

$$\delta_\partial = \sqrt{0{,}011_2 + 0{,}054^2 + 0{,}054^2 + 0{,}02^2 + 0{,}275^2},,$$

In the formula we marked:

δ_k - distance tolerance L_k between the axis of the sleeve pressed into the plate and the axis of the pin, δ_k = 0.012 mm;

S_1 - tool clearance in the replaceable sleeve, S_1 = 0.055 mm;

E_1 - eccentricity of the bushings, E_1 = 0.02 mm;

S_2 - landing clearance of the replaceable sleeve in the permanent sleeve, S_2 = 0.055 mm;

E_2 - error from the skew of the drill in the sleeve, E_2 = 0.285 mm.

so

$$\delta_{\ddot{a}} = 0{,}043\,mm; \delta_{\ddot{a}} \le \delta\,.$$

We determine the tolerance value $\delta^{/}_{\partial}$ at a distance $L^{/}_{\partial}$ between the two holes of the part:

$$\delta^{/}_{\partial} \ge \sqrt{\delta_k^2 + S_1^2 + S_2^2 + (S_1^{/})^2 + (S_2^{/})^2 + E_1^2 + E_2^2 + (E_2^{/})^2}\,,$$

$$\delta^{/} = \sqrt{\begin{array}{l} 0,04^2 + 0,054^2 + 0,054^2 + 0,054^2 + \\ +0,054^2 + 0,02^2 + 0,285^2 \cdot 2 \end{array}} = 0,0406\ mm.$$

In the formula we marked

δ_k - tolerance on the distance between the axes of the pressed bushings;

S_1 - slit of adjustment of a drill in the replaceable plug;

$S_1^{/}$ - clearance of adjustment of a drill in the plug;

S_2 - clearance adjustment of the replaceable sleeve in the stationary sleeve;

$S_2^{/}$ - clearance adjustment of the replaceable sleeve in the stationary sleeve;

E_1 - eccentricity of bushings.

The design of the device provides the condition $\delta_{\partial} > \delta^{/}$. The device provides the required accuracy.

3.2 Calculation of the four-spindle drilling head

The drilling head will be used on the machine tool. The kinematic scheme of the drilling head is based on the principles of internal gearing (Fig. 3.2).

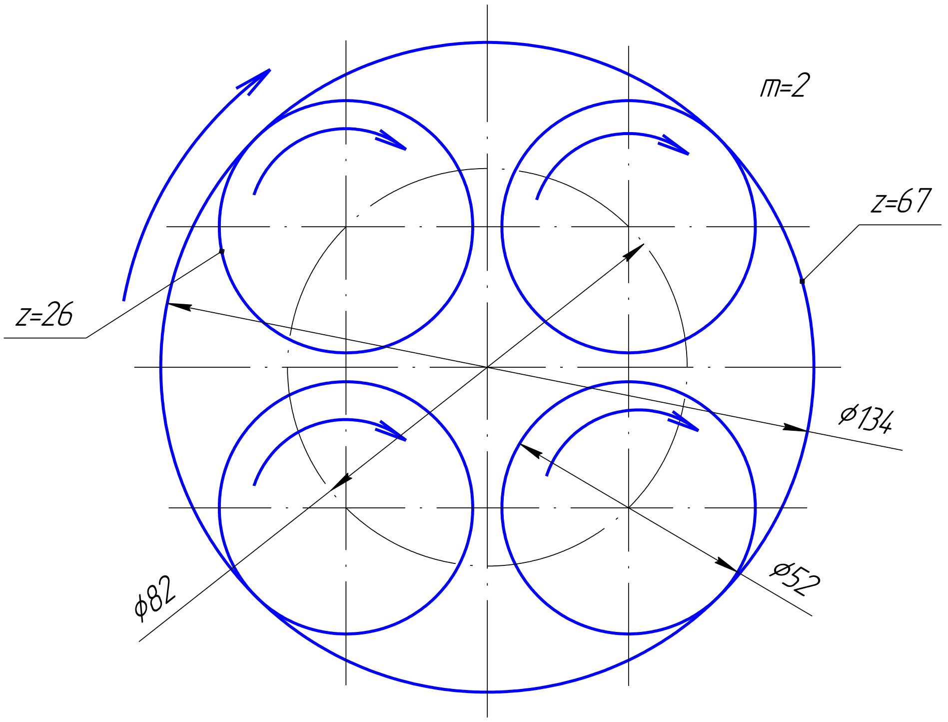

Figure 3.2 - Kinematic diagram of the drilling head

Machine spindle rotation:

$$460 \cdot \frac{26}{67} = 178{,}5\, rpm.$$

Valid speed according to the machine passport:

$$n_{\ddot{a}} = 180\, rpm.$$

Actual drill speed:

$$180 \cdot \frac{67}{26} = 464 \text{ rpm},$$

$S_{\tilde{o}\hat{a}} = 111 \text{mm / min}, V = 9{,}9\, m / min.$

We determine the axial force, torque and drilling power using the method [26].

Axial force for one drill:

$$P_o = 10 C_p D^q S^y K_p = 10 \cdot 42{,}7 \cdot 6{,}8^1 \cdot 0{,}24^{0{,}8} \cdot 1 = 927\, N.$$

Total axial force (for four tool spindles):

$$P = 4P_0 = 3708\,N.$$

Total torque that occurs when drilling four drills:

$$M = 4 \cdot 10 \cdot C_M \cdot D^q \cdot S^y \cdot K_p = 40 \cdot 0{,}021 \cdot 6{,}8^1 \cdot 0{,}24^{0{,}8} \cdot 1 = 1{,}82\,Nm.$$

Cutting power:

$$N = \frac{1{,}82 \cdot 464}{9750} = 0{,}087\,kW.$$

The diameter of the shaft of the central spindle

$$d_1 = \sqrt{\frac{16M_{\kappa p}}{\pi[\tau]}},,$$

where [τ] is the allowable torsional stress for steel 1044, [τ] = 20 kgf / cm2.

$$M_k = \frac{71620N}{n} = \frac{71620 \cdot 0,087}{180} = 34,6\,\kappa g / cm^2 = 346H / mm^2.$$

so

$$d_1 = \sqrt{\frac{16 \cdot 346}{\pi \cdot 20}} \approx 9{,}4\,mm.$$

The constructive size is specified $d_1 = 20\,mm.$

Drive gear module: $m = 2\,mm.$

The width of the gears is a multiple of 10 modules. Therefore, the specified design size is equal to B = 20 mm.

Diameter of the tail of the working spindles:

$$D = 1{,}3 \cdot 6{,}8 = 8{,}84\,mm.$$

The constructive size is specified $D = 20$ mm.

The diameter of the intermediate rollers of the spurious gears is equal to the diameter of the input shaft.

$$D_1 = 20 \text{ mm.}$$

We choose bearings using the values of the diameter of the shafts on which they are mounted. Then we will check them by the efficiency factor C.

We choose radial bearings of the middle series for the leading spindle:

№304, $C_r = 15{,}9\,kN, C_0 = 7{,}8\,kN;$

$$\text{№304,} \qquad C_r = 33{,}2\,kN, C_0 = 18\,kN.$$

We choose the following bearings for tool spindles:

deep groove ball bearings: №304, $C_r = 15{,}9\,kN, C_0 = 7{,}8\,kN;$

thrust bearings: №8204, $C_0 = 30\,kN.$

Conclusions to the section

In this section, we performed calculations of a four-spindle drilling head and a four-hole drilling device used on AG1 machines.

4 LIFE SAFETY AND FUNDAMENTALS OF LABOR PROTECTION

4.1 Development of measures to reduce noise at the site

Protection against industrial noise is important for improving working conditions and increasing its productivity [16, 17]. There are many different means to reduce the noise from units and machines. One of them is the replacement of the shock process by a shockless one. So the reciprocating motion of the parts of the units must be replaced by rotating. If there is noise from the vibration of impact parts and individual components, individual components must be treated with materials with high internal friction (rubber, cork, bitumen, felt). Interleaving metal parts with plastic or other noise-free materials is also effective. With significant noise in the guide tubes (turret machines and others), it is advisable to arrange flexible connections between the rod and the tube, which are essentially damping devices that reduce vibration and noise.

Where there are fans, ejectors, blowers and other installations with air jets, it is necessary to make flexible transitions on air ducts from fabric, and flanges - from rubber. Significantly reduces the noise of lubrication of impact parts with viscous liquids. To reduce noise in the gearboxes, they are placed in liquid, oil and other baths. If it is not possible to reduce the noise at the source to its permissible level, the unit design must include devices that prevent the spread of noise to the outside, ie insulate or absorb it. For units (electric motors, gear reducers, etc.) are placed in soundproof enclosures with outlet controls and controls and, if possible, to automatically control the operation of these units; noisy units of the unit - gear reducers, chain, belt and other transmissions, impact parts, engines, etc. - placed in insulating boxes and casings; the necessary openings in sound-insulating casings are made in the form of the channels lined from within with sound-absorbing materials; all units that create excessive noise due to vortex formation or exhaust of air and gases (fans, blowers, pneumatic tools, etc.), be equipped with special chambers.

With the right choice and installation of the fan, you can create a completely silent ventilation of industrial premises. Fans usually run at high speeds (up to 2000 rpm), which leads to significant vibrations. The noise of the ventilation unit spreads to neighboring rooms in three main ways: through ventilation ducts; through walls, windows or other fences; on a design of the room in the form of vibrations. To reduce the noise, it is necessary to choose low-noise fans, install silencers in the air ducts, provide sufficient sound insulation of the ventilation chamber and the walls of the air ducts and, if necessary - vibration insulation of the unit.

Noise reduction can also be achieved by acoustic treatment of the room [11]. Acoustic treatment of the room involves covering the ceiling and upper walls with sound-absorbing material. As a result, the intensity of the reflected sound waves decreases. In addition to the ceiling, sound-absorbing boards, cones, cubes can be hung, resonator screens, ie artificial absorbers can be installed. The efficiency of acoustic treatment of premises depends on the sound-absorbing properties of materials and structures, their location, volume, geometry, location of noise sources. Measures to reduce noise should be provided at the design stage of industrial facilities and equipment. Particular attention should be paid to the removal of noisy equipment in a separate room, which reduces the number of employees in conditions of high noise and take measures to reduce noise with minimal costs, equipment and materials.

4.2 Measures for fire safety of the designed site

Prevention of the spread of fires is mainly determined by the fire safety of buildings and structures and is ensured by: the correct choice of the required degree of fire resistance of building structures; correct spatial planning decisions of buildings and structures; location of premises and productions taking into account fire safety requirements; installation of fire barriers in buildings, ventilation systems, fuel and cable communications; restriction of leakage and spreading of flammable liquids in case of fire; installation of smoke protection; design of evacuation routes; measures for the successful deployment of tactical actions to extinguish the fire.

When designing and building industrial enterprises, it is necessary to provide measures to prevent the spread of fire, namely:

- division of the building by fire-fighting floors into fire compartments;
- division of the building by fire partitions into sections;

- installation of fire barriers to limit the spread of fire on structures, combustible materials (ridges, sides, belts);
- installation of fire doors and gates;
- arrangement of fire breaks between buildings.

For division of the building into fire compartments instead of fire walls fire zones which are carried out in the form of an insert on all width and height of the house are allowed. The insert is a part of the volume of the building, which is formed by fire walls (minimum fire resistance limit 0.75 hours). The width of the zone is not less than 12 m. Combustible substances are not allowed to be stored within the zone. Vertical diaphragms and water curtains are provided on the boundaries of the zone with fire compartments in accordance with SNiP 2.04.09-84 [17]. Within the zone, fire escapes are placed on the roof, and in the outer walls of the zone - doors or gates.

Holes in fire walls, partitions and ceilings must be equipped with protective devices (fire doors, fire doors, fire valves, water curtains) against the spread of fire and combustion products. It is not allowed to install any devices that interfere with the normal closing of fire and smoke doors, as well as to remove devices for their self-closing. When drawing up master plans of enterprises from the point of view of fire safety, it is important to ensure appropriate distances from the boundaries of enterprises to other enterprises and buildings. Fire-fighting distances between buildings must prevent the neighboring building from catching fire during the time required to activate the fire extinguisher.

Appropriate substances (plaster, special paints, varnishes, coatings) are used to protect metal, wood and polymer structures. Reducing the flammability of polymeric materials is achieved by introducing fillers, flame retardants, application of fire-retardant coatings. Chalk, kaolin, graphite, vermiculite, perlite, expanded clay are used as fillers. Flame retardants protect wood and polymers. When heated, they emit non-combustible substances, preventing the decomposition of wood and the release of flammable gases. After the expiration date and in case of loss or deterioration of fire-retardant properties, the treatment (impregnation) must be repeated.

CONCLUSIONS

The technological process of manufacturing the flange 753.172.004 is developed and the technological equipment for its realization is designed. In particular, the type of production was determined and the manufacturability of the part was analyzed, the method of obtaining the workpiece was chosen and its main dimensions were calculated, the design of sequences of workpiece surface treatment and operational technological process of part manufacturing was performed. On the basis of the operational technological process of manufacturing the part, the choice of machine equipment is made, the cutting modes are determined. To improve the machine tool, calculations and design of the machine tool for fixing the part on the technological operation of machining were performed. Measures have been developed to ensure working conditions and safety in emergency situations during the manufacture of such a part.

LIST OF REFERENCES

1. Anuriev, VI Handbook of the designer-machine builder / VI Anuriev. In 3 volumes vol. T.1. Ed. 6 th revision. and additional. - M .: Mechanical Engineering, 1982. - 736 p.

2. Gorbatsevich, AF Course designing in engineering technology:Textbook for high schools / AF Gorbatsevich, VAShkred Izd. 5th - M .: Alliance, 2007. - 256 p.

3. Diploma design on technology of machine building / Ed. VV Grandma - Minsk: Higher school, 1979. - 464 p.

4. Dobryansky, SS Technology of mechanical engineering and technological bases of mechanical engineering / SS Dobryansky, VK Frolov, Yu.M. Malafeev, VM Gritsenko - K .: NTUU "KPI", 2007. - 72 p.

5. General machine-building standards of time and cutting modes for standardization of work performed on universal and multi-purpose machine tools with CNC. / Part 2. Rules of cutting modes. - Moscow: Economics, 1990. - 474 p.

6. Gorbatyuk, EO Technology of mechanical engineering. / EO Gorbatyuk, MP Mazur, AS Zenkin, VD Karazey - K .: "New World", 2009. - 360 p. 15.

7. Ilyankov, AI Engineering Technology: Practicum and course design. / AI Ilyankov, V.Yu. Novikov - Moscow: Academy, 2012. - 432 pp.

8. Vasylkiv V., Danylchenko L., Radyk D. Technological methods of manufacturing workpieces. Casting: Manual. Edited by L. Dzhydzhor. Ternopil: Aston, 2021, 205 p.

9. Creating a 3D model. Study guides for lab classes № 4 in the “CAM and CAE Systems of Machine Building Production” course.Editors:Vasylkiv V., Danylchenko L., Radyk D. -Ternopil: Ternopil National Ivan Puluj Technical University, 2021. - 40 p.

10. Creating a parametric drawing in the automatic parameterization mode.Study guides for lab classes № 3 in the “CAM and CAE Systems of Machine Building Production” course.Editors:Vasylkiv V., Danylchenko L., Radyk D. -Ternopil: Ternopil National Ivan Puluj Technical University, 2021. - 28 p.

11. Creating Parametric Drawing.Study guides for lab classes № 2 in the “CAM and CAE Systems of Machine Building Production” course.Editors:Vasylkiv V.,

Danylchenko L., Radyk D. -Ternopil: Ternopil National Ivan Puluj Technical University, 2021. - 38 p.

12. Sketching by Non-parametric Drawing.Study guides for lab classes № 1 in the “CAM and CAE Systems of Machine Building Production” course.Editors:Vasylkiv V., Danylchenko L., Radyk D. -Ternopil: Ternopil National Ivan Puluj Technical University, 2021. - 28 p.

13. Creating a 3D model from a 2D drawing. Study guides for lab classes № 5 in the “CAM and CAE Systems of Machine Building Production” course.Editors:Vasylkiv V., Danylchenko L., Radyk D. -Ternopil: Ternopil National Ivan Puluj Technical University, 2021. - 39 p.

14. Vasylkiv V., Pylypets M., Danylchenko L., Radyk D. (2021) Use of computer-integrated technologies in training of engineering specialists. In: Ternopil National Ivan Puluj Technical University, Proceedings of the International Conference Advanced Applied Energy and Information Technologies, Ternopil, December 15-17, 2021, pp. 74-80.

15. Vasylkiv V., Danylchenko L. Factors influencing the value of spring back of sheet material in bending. Materials of the International scientific and technical conference "Fundamental and applied problems of modern technologies" to the 100th anniversary of the foundation of the National Academy of Sciences of Ukraine and to the commemoration of Ivan Puluj (100th anniversary from the day of death) (Tern ., 22-24 May 2018), pp. 84-85.

16. Health and Safety Executive information sheet. Safe use of horizontal boring machines Engineering Information Sheet No 28 (Revision 1). This document is available at: www.hse.gov.uk/pubns/eis28.pdf.

17. Safety and health in the use of machinery. ILO code of practice Geneva, International Labor Office, Program on Safety and Health at Work and the Environment, 2013.

18. Ibrahim A. Al-Zkeri, MS Finite element modeling of hard turning. The Ohio State University, 2007.

19. Mikell P. Groover. Fundamentals of Modern Manufacturing. Materials, Processes, and Systems. Fifth Edition. John Wiley & Sons, Inc., 2013.

20. Kalpakjian, S., and Schmid SR Manufacturing Processes for Engineering Materials, 6th ed. Pearson Prentice Hall, Upper Saddle River, New Jersey, 2010.

21. Groover, MP Work Systems and the Methods, Measurement, and Management of Work, Pearson Prentice-Hall, Upper Saddle River, New Jersey, 2007.

22. Groover, MP Automation, Production Systems, and Computer Integrated Manufacturing, 3rd ed. Pearson Prentice-Hall, Upper Saddle River, New Jersey, 2008.

23. Boothroyd, G., and Knight, WA Fundamentals of Metal Machining and Machine Tools, 3rd ed. CRC Taylor & Francis, Boca Raton, Florida, 2006.

24. Bakerjian, R. (ed.). Tool and Manufacturing Engineers Handbook. 4th ed. Vol VI, Design for Manufacturability. Society of Manufacturing Engineers, Dearborn, Mich., 1992.

25. Parsai, H., Leep, H., and Jeon, G. The Principles of Group Technology and Cellular Manufacturing, John Wiley & Sons, Hoboken, New Jersey, 2006.

26. A handbook of a technologist-machine builder in 2 volumes of T1. Ed. AG Kosilova and RK Meshcheryakova - 4th ed. Recycled and supplemented - M .: Mashinostroenie, 1986. - 656 p.

27. A handbook of the technologist-machine builder In 2 volumes of T2. Ed. AG Kosilova, RK Meshcheryakova - 4th ed. Recycled and supplemented - M.: Mashinostroenie, 1986. - 496 p.