Vinnytsia National Technical University
(full name of higher education institution)

Faculty of Mechanical Engineering and Transport
(full name of the institute, name of the faculty (department))

Department of Technologies and Automation of Mechanical Engineering
(full name of the department (subject, cycle commission))

MASTER'S QUALIFICATION THESIS

on the topic:

DESIGN OF AN AUTOMATED WORKPLACE FOR THE TECHNOLOGICAL PROCESS OF MACHINING OF THE PART "SUPPORT"

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Performed by: student of the 2nd year,
group 3PM-24m
specialties 131 – Applied Mechanics
(code and name of the direction of training, specialty)
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Vinnytsia National Technical University
Faculty of Mechanical Engineering and Transport
Department of Technologies and Automation of Mechanical Engineering
Level of higher education II (Master's)
Field of knowledge – 13 - Mechanical Engineering
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Head of the Department of TAME
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T A S K
FOR THE STUDENT'S MASTER'S THESIS

Yang Lifeng
(full name)

1. The topic of the thesis. «Design of an automated workplace for the technological process of machining of the part "Support"»
supervisor Ph.D., docent, associate prof. of dep. of TAME Lozinskyi Dmytro
approved by the order №95 of the higher educational institution from 20.03.2025 year

2. Deadline for submission of thesis by the student 18 of June 2025 year.

3. Initial data for thesis: working drawing of the part "Support", drawing of the blank, production program of 6500 pcs.

4. Content of the text part: overview of methods and means of automation of production; development of a scheme of an automated workplace for machining a Support part in a milling operation with a CNC; algorithm of operation of an automated workplace for machining a Support part in a milling operation with a CNC; automation of production elements; economic justification of the development.

5. List of illustrative material (with exact indication of mandatory drawings): purpose and objectives of the work; drawing of the part, drawing of the blank, route of machining of the part, dimensional analysis, review of existing automated workplaces for machining; diagram of the automated workplace and algorithm of work; debugging map; study of the characteristics of the work of an industrial robot; layout of the automated workplace; algorithm of operation and cycle diagram of the work of the automated workplace; conclusions

6. Consultants of thesis chapter

Chapter	Surname, initials and position of the consultant	Signature, date	
		issued the task	execution accepted
Special part	Ph.D., docent, associate prof. of dep. of TAME Dmytro LOZINSKYI	07.04	06.06
Economic part	Ph.D., docent, associate prof. of dep. of BEPM Viacheslav KAVETSKIY	16.04	03.06

7. Issue date of the task 20.03.2025 y.

CALENDAR PLAN

№	The title of the stages master's qualification work	The term of performance of work stages	Note
1	Defining the object and subject of research	until 11.04.2025	done
2	Analysis of known solutions, setting tasks	until 15.04.2025	done
3	Technical and economic justification of research methods	until 16.04.2025	done
4	Solving the tasks set	until 30.05.2025	done
5	Formulation of conclusions on the work, scientific novelty, practical value of the results	until 05.06.2025	done
6	Completion of the section "Economic part"	until 03.06.2025	done
7	Preliminary defense of the MQT	until 09.06.2025	done
8	Checking the work for plagiarism	until 10.06.2025	done
9	Standard control of the MQT	until 11.06.2025	done
10	Reviewing the MQT	until 13.06.2025	done
11	Defense of the MQT	until 30.06.2025	done

Student Lifeng YANG Lifeng YANG

Supervisor Dmytro LOZINSKYI

АНОТАЦІЯ

Ян Ліфен Проектування автоматизованого робочого місця технологічного процесу механічної обробки заготовки деталі "Упор". Магістерська кваліфікаційна робота зі спеціальності 131 – прикладна механіка. Вінниця ВНТУ, 2025, 69с.

На англ. мові. Бібліограф.: 28 назв; рис. 35; табл. 13.

Кваліфікаційна магістерська робота містить матеріали, присвячені розробці автоматизованого робочого місця для технологічного процесу механічної обробки деталі «Упор». У роботі наведено огляд методів і засобів автоматизації в сучасному технологічному виробництві, основні тенденції їх розвитку, на основі яких запропоновано концептуальну схему автоматизованого робочого місця та алгоритм його функціонування.

Розроблено маршрут обробки, розраховано режими різання та припуски на обробку плоских і циліндричних поверхонь. На основі аналізу маршруту визначено операції, для яких було розроблено автоматизоване робоче місце, та запропоновано алгоритм його роботи.

Проведено дослідження продуктивності автоматизованого робочого місця, а також вивчено вплив конструктивних параметрів промислових роботів на час виконання операцій.

Визначено комерційний потенціал дослідження та оцінено капітальні витрати на модернізацію ділянки механічної обробки. Проведено оцінку економічної ефективності інноваційного рішення.

Ключові слова: промисловий робот, автоматизація, технологічний процес, упор, час роботи.

ABSTRACT

Yang Lifeng Design of an automated workplace for the technological process of machining of the part "Support". Master's qualification thesis on specialty 131 - applied mechanics. Vinnytsia VNTU, 2024, 69 p.

Bibliography: 27 titles; Fig. 35; table 13.

The master's qualification thesis presents materials devoted to the development of an automated workplace for the technological process of machining the "Support" workpiece. The thesis includes a review of methods and means of automation in modern technological production, the main trends in their development, based on which a conceptual scheme of the automated workplace and its operating algorithm are proposed.

Machining route was developed, cutting modes and allowances for machining flat and cylindrical surfaces were calculated. Based on the route analysis, operations were identified for which the automated workstation was developed, and the algorithm of its operation was proposed.

Research has been conducted on the performance of the automated workplace, and the influence of the design parameters of industrial robots on the operation time of operations has been investigated.

The commercial potential of the research and the estimate of capital expenditures for the modernization of the mechanical processing area have been determined. An assessment of the economic efficiency of the innovative solution has been carried out.

Keywords: industrial robot, automation, technological process, support, working time.

CONTENTS

INTRODUCTION

The development of production and the improvement of its characteristics are an integral part of the development of any state.

Today, industrial robots are a relevant technology for the development of flexible and reconfigurable manufacturing systems that allow for the automatic performance of operations such as milling, cutting, drilling, grinding, deburring, and polishing [1, 2].

Relevance of the topic.

Automation of production processes using robotic systems is changing the general perception of production systems. Industrial robots are a reliable technology both for creating fully automated systems that solve various production tasks, and for improving existing small production sites.

The introduction of robotic elements into production processes is constantly growing worldwide, and forecasts indicate that this trend will continue in the future [1 - 3].

The issues of automation of various elements of production are discussed in the works of Kozlov L.G., Pavlenko P.M., and Mulyar Y.I. The works of the authors Pavlenko I.I., Mazhara V.A., Tsvirkun L.I., Isak Karabegović and others consider the issues of application of automation and robotization in manufacturing industries [1-6].

However, automation elements are constantly being improved, so research devoted to the automation of production elements is a relevant task [7-9].

Connection of work with state scientific programs, plans and topics. The master's thesis was completed in accordance with the research topics of the Department of "Technology and Automation of Mechanical Engineering" (TAME) of Vinnytsia National Technical University (VNTU) in accordance with the research work of the Department No. 17K2/14 "Development, research and improvement of the characteristics of energy-saving hydraulic drives of technological and mobile machines" (2024-2028).

The purpose of the work is the automation of the workplace of the technological process of machining the workpiece of the "Support" part.

To achieve this goal, you need to complete the following tasks:

-to review known methods and means of automation used in technological production;

- develop a machining route;

- determine the parameters of machining;

- analyze the machining route and identify operations that can be automated;

- develop a general diagram of an automated workplace and an algorithm for the operation of an automated workplace;

- select technological equipment and design automated equipment for it;

- perform calculations of the main parameters of the automated workplace;

- develop the layout of an automated workplace;

- to calculate and analyze the economic feasibility of manufacturing the part;

Research object–automated workplace technological process of machining the workpiece of the "Support" part.

Subject of study– technological process of machining the “Support” part.

Research methods. Methods of analytical and simulation modeling, mathematical modeling and calculation of operating parameters of an automated workplace, determination of the characteristics of an automated workplace in analytical and graphical form.

Scientific novelty of the obtained results:

- the method of calculating the time spent on performing operations in an automated workplace of the technological process of machining a workpiece "Support" has been further developed by taking into account the empirical dependences of the speed of execution of the main movements of the robot manipulator on its design parameters and settings.

Practical significance of the results obtained:

1. A route for mechanical automated machine tool equipment for CNC milling operations has been developed.

2. The layout of the automated workplace of the technological process of machining the workpiece "Support" has been developed.

3. The time costs were calculated and a cycle diagram of the functioning of the automated workplace of the technological process of mechanical processing of the workpiece "Support" was constructed.

4. Practical recommendations are formulated for the selection of design parameters of an industrial robot for adjusting the speed parameters of performing operations.

Personal contribution of the applicant. The main results of research on the developed layout of the workplace. The purpose and objectives of the research, the scheme of the workplace are agreed with the scientific supervisor. In the works published in co-authorship, the author includes: calculations of the main indicators and search for information resources.

Approbation of the results of the dissertation. The main results of the work were considered at the conference "IV International Scientific and Technical Conference "Prospects for the Development of Mechanical Engineering and Transport - 2025"

Publications. The material of the master's qualification work was published in - abstracts of conference reports [26].

1 OVERVIEW OF METHODS AND MEANS OF PRODUCTION AUTOMATION

1.1 Overview of existing methods and means of production automation

Industry is constantly improving and improving its efficiency, which is the key to its profitability. In the mechanical engineering industry, industrial robots are usually used to solve the following typical tasks [10-12]:

• as an integral part of modern production lines, which are designed with a high degree of automation and flexible characteristics;

• for the integration of already installed production facilities, where the use of industrial robots significantly increases the efficiency of the enterprise, ensuring its productivity [2].

Let us consider the main examples of application in production.

The authors of the work [2] analyzed the use of industrial robots for various auxiliary tasks, such as tool change (Fig. 1.1) or workpiece positioning (Fig. 1.2)

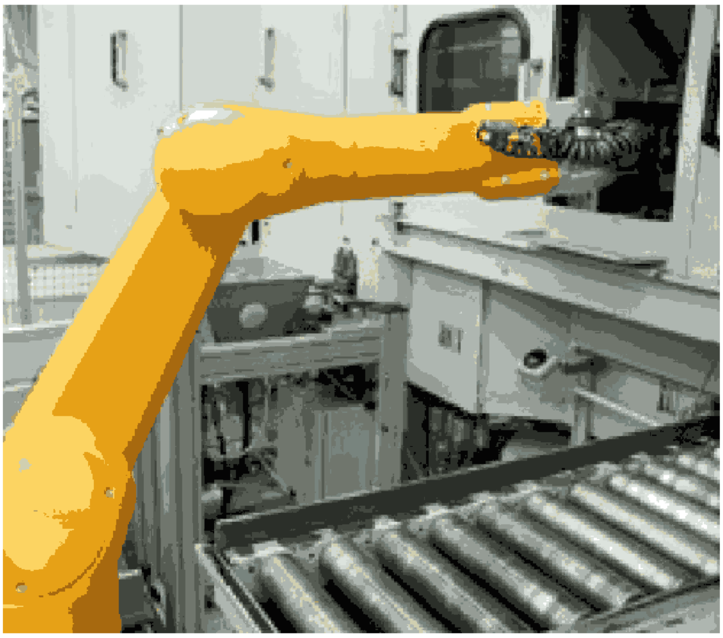


Figure 1.1 – Application of industrial robots for tool changing

Figure 1.2 – Application of industrial robots for re-installation of the blank

The use of one robot to perform tasks is a fairly cost-effective solution, which allows for faster and more efficient synchronization of the work of automated equipment when changing parts being processed.

The paper presents analytical studies on the geometry of robotic equipment. From the point of view of performing typical tasks in machine-building production, it is necessary that the robot has six degrees of freedom and the ability to change gripping devices for holding workpieces (Fig. 1.3).

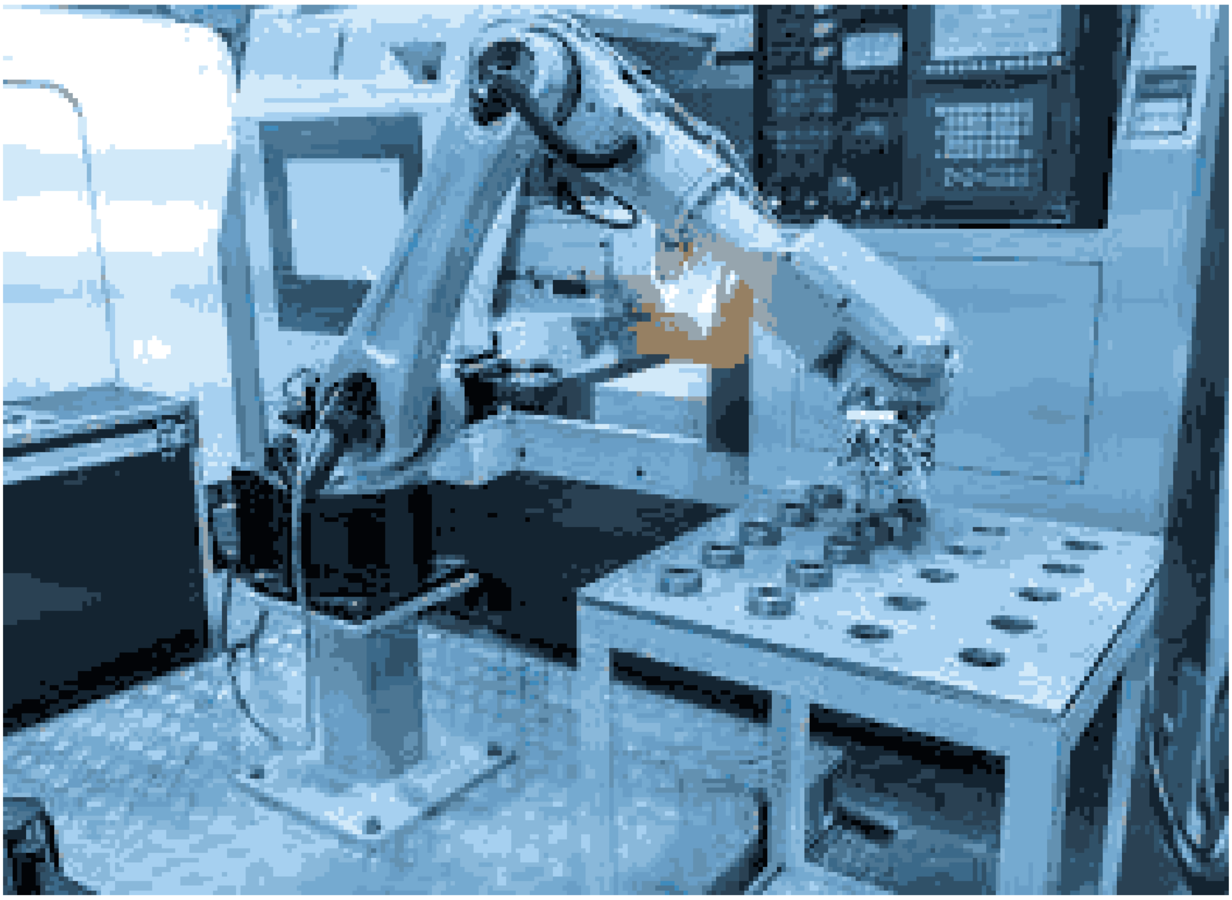


Figure 1.3 – Application of industrial robots in mechanical engineering

The authors of the work [1] conducted a fairly thorough analysis of the suitability of different types of robots for performing various tasks in mechanical engineering

In particular, the use of robotic workplaces for mechanical processing was investigated and it was found that such automated workplaces are used in various industrial sectors and are able to solve key production tasks for a wide range of products. The successful implementation of industrial robots covers a large number of industries. The use of robots as the main equipment of an automated workplace was investigated.

Although the use of such an option has positive qualities, it is often limited by the properties of the processed material, which, in particular, is a consequence of the insufficient rigidity of robotic equipment for performing edge processing directly (Fig. 1.5)

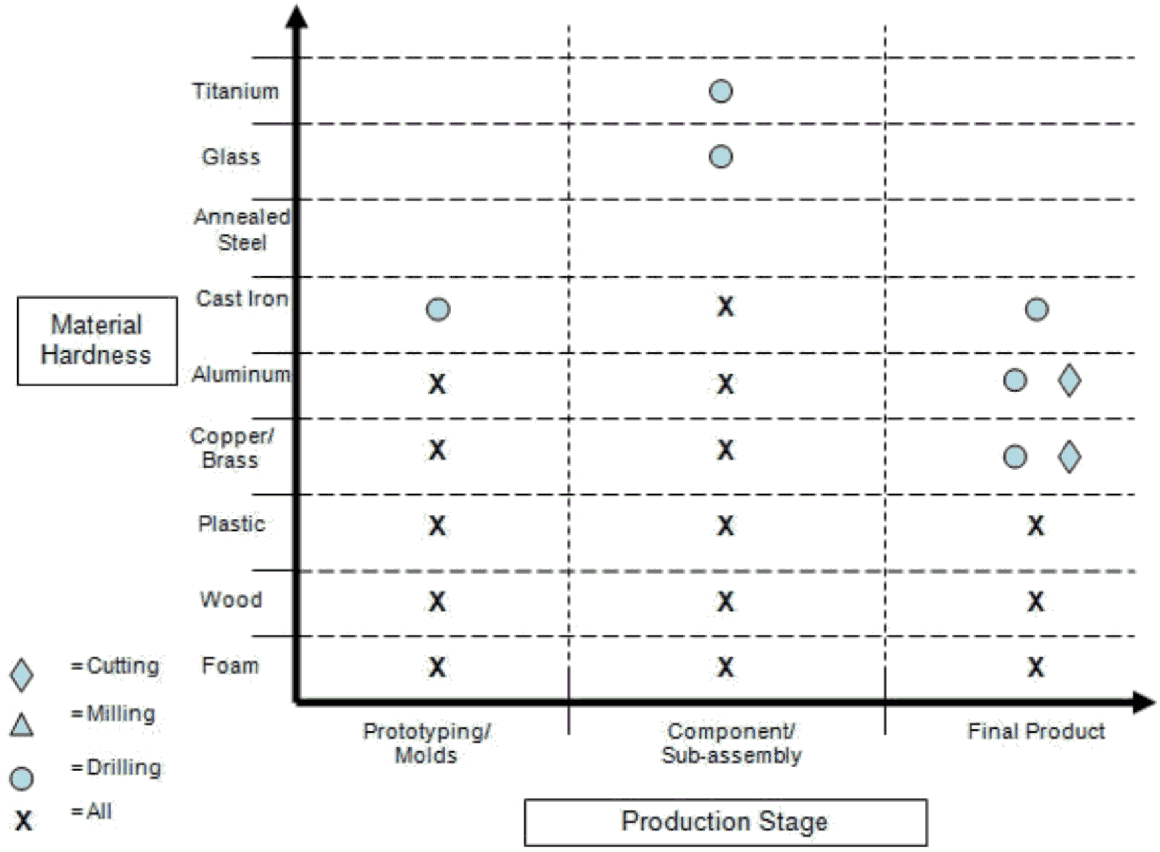


Figure 1.5 – Application of robots for material handling

In [13], a complex of robotic equipment and a machine tool with numerical program control for performing milling operations (Fig. 1.6).

A feature of this development is the use of an integrated approach, both to the selection of components of the complex and to the application of automation in general. Since it is proposed to apply automation elements not only to the production process, but also to the process of programming its elements and technological preparation of production in general.

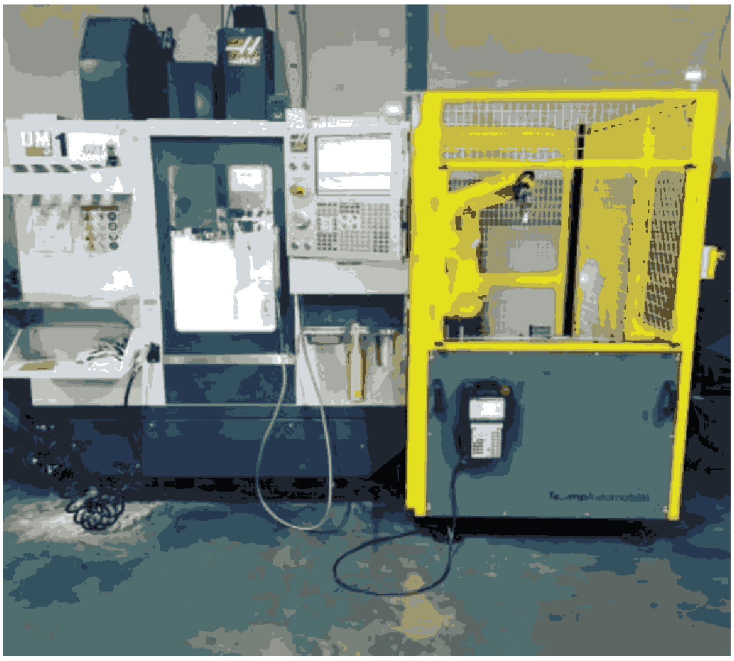


Figure 1.6 – Milling robotic technological complex based on the HAAS DM-2 machine tool

In work [14], the authors considered several options for the layout of the complex and conducted research into the optimal option of robotic equipment and a machine tool with numerical program control for performing turning operations (Fig. 1.7).

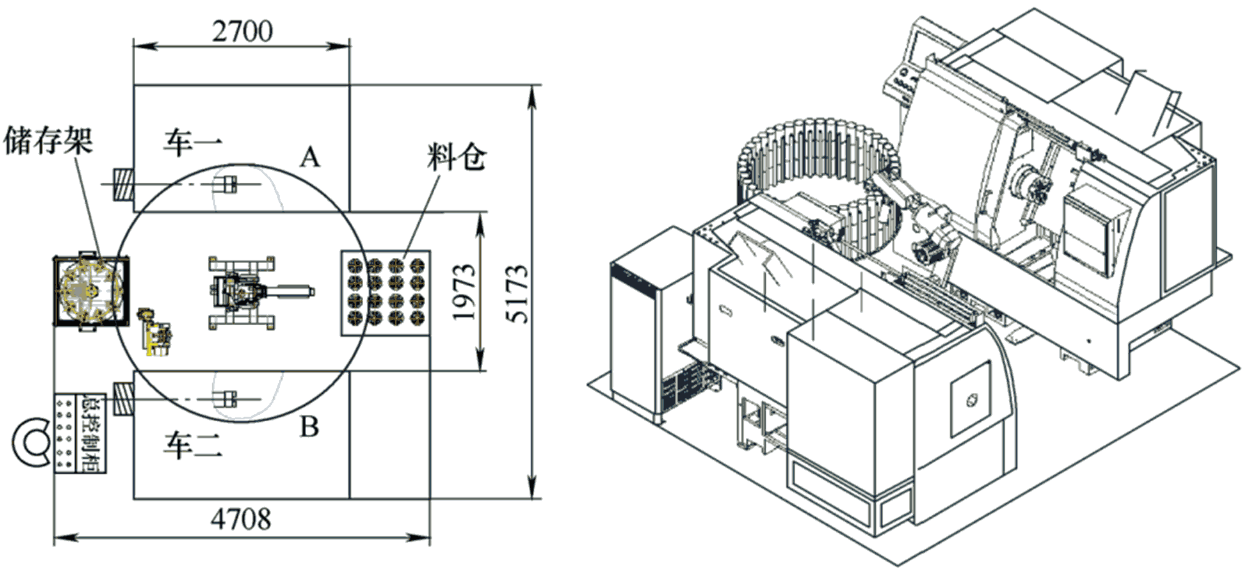


Figure 1.7 – Lathe robotic technological complex

1.2 Conclusions to the section

1. Based on the review of the application of various automation tools, the main methods for the means of production automation can be distinguished, namely the use of robotic equipment and auxiliary equipment in combination with CNC machine tool equipment.

2. Automated or robotic elements usually perform auxiliary functions.

3. Robots with 4-6 degrees of freedom are usually used to service the machine tool

4. In the workplace, industrial robots perform the primary tasks of automation and - automate unloading and loading operations.

2 DEVELOPMENT OF A SCHEME OF AN AUTOMATED WORKPLACE FOR MECHANICAL PROCESSING OF SUPPORT PARTS IN CNC MILLING OPERATION

2.1 Development of a technological process for machining a part “Support”

2.1.1 Selection of methods, sequence and number of passes for processing individual surfaces

The correct choice of technological bases at this stage of design largely determines the achievement of the required accuracy of the part during its manufacture and the cost-effectiveness of the processes.

According to the recommendations for designing technological processes of mechanical processing, first the selection of finishing technological bases is performed, that is, such surfaces that are used in performing most operations of the technological process. In this case, the task of ensuring the basing errors of the performed dimensions equal to zero or reducing them to minimum values is solved..

2.1. Selection of finishing technological bases.

The main base surfaces are the center holes and one of the ends. It is desirable that the design and technological bases coincide. In this case, the basing error is zero. This option for choosing bases is optimal.

To correctly select finishing bases, it is necessary to analyze all machining operations in order to select the best basing option. In operation 015, CNC lathe, we process surfaces∅30H7, M20-g7, ends (2), (4), surfaces (5), (6) and chamfer 1.5×45°(7) (Fig. 2.1). Basing of the part is carried out in the centers.

$\varepsilon_{\delta_{м20-g7}} = 0$,, $\varepsilon_{\delta_{\Theta 30h7_{-0.021}}} = 0$ machining of diametrical size, accuracy is ensured by tool setting

$\varepsilon_{65} = 0$ combination of technological and measuring bases

$\varepsilon_{\delta_{410}} = 0$ The surface given the specified size is planned to be processed with one installation..

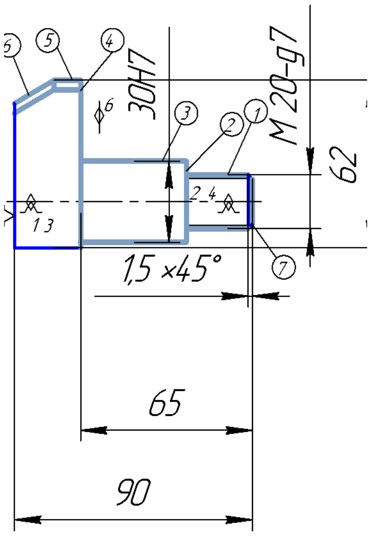


Figure 2.1 – Finished technological bases

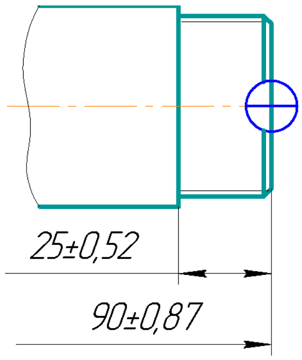


Figure 2.2 – Part dimensions

When machining in centers on a rigid front center, a basing error occurs, which is equal to the tolerance for the T_{90} size plus the center error, i.e., for size 25±0.52:

$$\Delta C = \sqrt{\left(\frac{\delta_3}{2}\right)^2 + 0{,}52^2} = 0{,}5\ mm.$$

$$\varepsilon\delta_{25} = T_{90} + \Delta\surd = 0.87 + 0.5 = 1.37 \text{ mm}.$$

$$\varepsilon\delta_{25} > T25; 1.37 \text{ mm} > 1.04 \text{ mm}.$$

The processing conditions for accuracy are not met.

It is necessary to adjust the tolerances of the component dimensions.

When using a front floating center, the centering error C=0 and the basing error are significantly reduced.

We process the left end in a similar way in turning operation 015. The grinding operation is carried out in the centers in a similar way.

Milling of surfaces and drilling of holes is carried out in a special fixture with installation in two prisms. In this case, a basing error occurs in the form of a displacement of the workpiece axis (ε_b)

$$\varepsilon_b = T_D \cdot \frac{1}{2 \cdot Sin\frac{\alpha}{2}} = 0.062 \cdot \frac{1}{2 \cdot sin\frac{90}{2}} = 0.043\ mm.$$

Size tolerance T35 = 0.062>0.043 mm.

The processing conditions for accuracy are met.

2.1.1 Selection of draft technological bases.

In the first operation, it is necessary to process the finishing bases, namely, to make center holes on the ends. To process the finishing bases, the workpiece is based on the rough bases (Fig. 2.3).

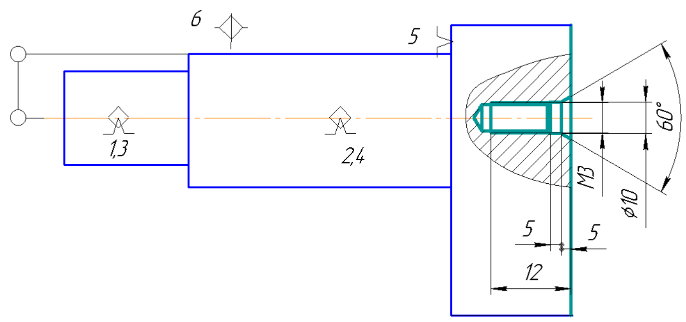


Figure 2.3 - 1st installation of the part

In operation 005, turning, we machine the ends and center the holes from two positions.

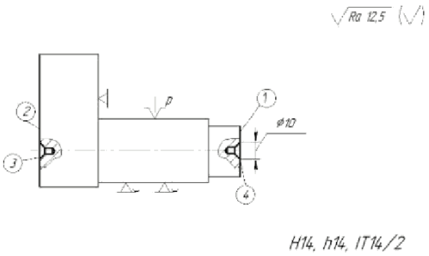
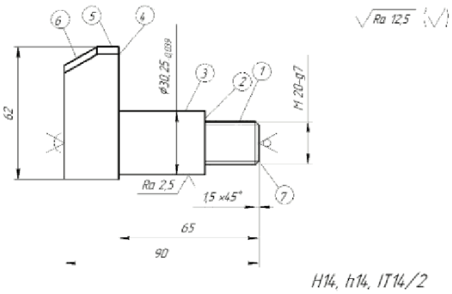
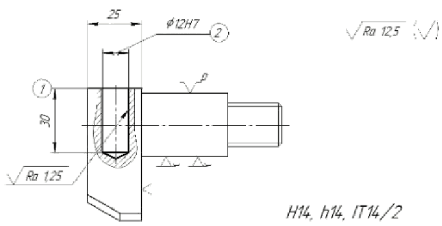
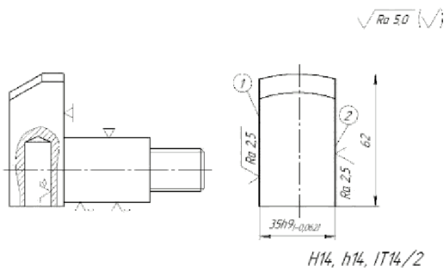
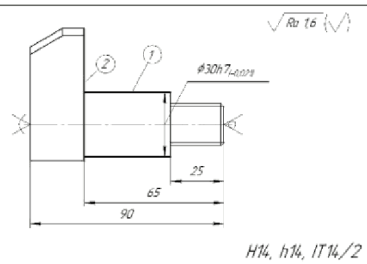
When installed in a 3-jaw chuck, the offset of the workpiece axis is □0 = 0. The basing error for the dimensions is $\varepsilon_{\delta 90} = 0$, because the bases coincide.

$\varepsilon\delta_{12} = T_{90} = 0.87$ mm. $\varepsilon\delta_{12} > T_{12}$ (0.87 mm >0.6 mm).

With the selected basing option, the problem is solved - the connection of unprocessed surfaces with processed ones.

2.1.4 Development of a mechanical route.

Table 2.1 – Machining route

№ operation	Operation name with number of transitions	Installation diagram	Equipment type and model
005	Milling and centering 1. Install and secure the part. 2. Mill ends 1 and 2 once. 3. Center holes 3 and 4 once. 4. Remove the part.		Milling and centering machine MR-71M
010	CNC lathe 1. Install and secure the part. 2. Grind surface 1, end 2 once, surface 3 preliminary and surface 3 final. 3. Grind end 4 preliminary. 4. Grind end 4 final. 5. Grind surfaces 5 and 6 once. 6. Grind chamfer 7 once. 7. Cut a thread on surface 1. 8. Remove the part.		CNC lathe 16K20F3
015	Vertical drilling with CNC 1. Install and secure the part. 2. Mill surface 1 once. 3. Center hole 2. 4. Drill hole 2 once. 5. Pre-drill hole 2. 6. Final drill hole 2. 7. Remove the part.		Vertical drilling with CNC 2R135F3
020	Vertical milling with CNC 1. Install and secure the part. 2. Mill surfaces 1 and 2 preliminarily. 3. Mill surfaces 1 and 2 finally. 4. Remove the part.		Vertical milling with CNC GF2171MF3
025	Heat treatment		
030	End-cylindrical grinding 1. Install and secure the part. 2. Grind surface 1 and end 2. 3. Remove the part.		End-round-grinding 3T160

2.1.5 Dimensional and precision modeling of the technological process

Dimensional analysis establishes relationships between operations and transitions of a given technological process and analysis of relationships. Dimensional relationships are defined and recorded in the form of dimensional chains.

We will perform dimensional analysis for operation 030.

The arrangement of technological dimensions is shown in Fig. 2.4.

After completing the construction of the dimensional scheme, dimensional chains are allocated for calculating unknown dimensions.

The value and accuracy of the closing link K1, K2… depends on the values and accuracy of the component dimensions of the chain B1, B2, B3…

The dimensions obtained in this operation have a quality of accuracy of 14, the accuracy of the dimensions of the workpiece is quality 14. The previously accepted tolerances are summarized in Table 2.2.

Table 2.2 – Preliminary tolerances of technological dimensions.

Size	B_1	B_2	B_3	B_4	B_5	B_6	W_1	W_2	W_3
Tolerance, mm	0,87	0,87	0,62	0,3	0,074	0,03	1,4	1,2	1

The determined tolerances are used in further calculations of technological dimensions.

One of the first stages of dimensional analysis is the construction of a dimensional diagram of the technological process.

2.1.5.1 Dimensional diagram of the technological process

The dimensional diagram indicates the dimensional parameters of the part at each operation and records changes in the dimensions K, B, and W.

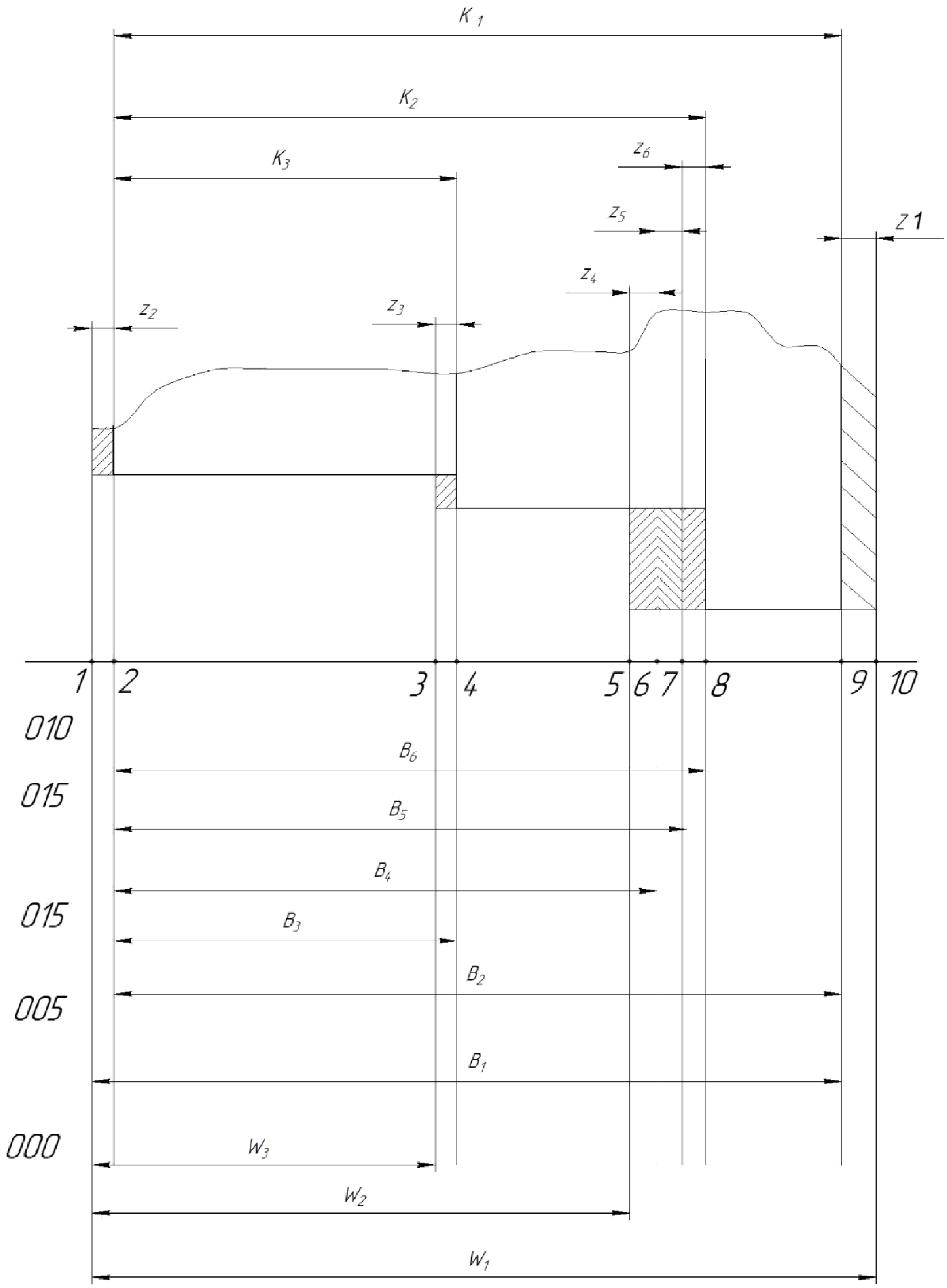


Figure 2.4 – Dimensional diagram of the technological process

2.1.5.2 Derivative, output graphs - trees, combined graph

If we consider the surfaces of the workpiece and the part as vertices, and the connections between them (dimensions) as edges, then the drawing of the part with design and technological dimensions can be represented as two trees. The tree with design dimensions and dimensions of machining allowances is called the original, and the tree with technological dimensions is called the derived or technological.

If both trees are combined, then such a combined graph allows you to present the geometric structure of the technological process of processing a part. In such a graph, all dimensional relationships and technological dimensional chains are transformed from implicit to explicit. It becomes possible not to refer to the drawing, but to carry out all the necessary calculations and research using only the information carried by the graph. Any closed loop on the combined graph, consisting of the edges of the original and technological trees, creates a technological dimensional chain.

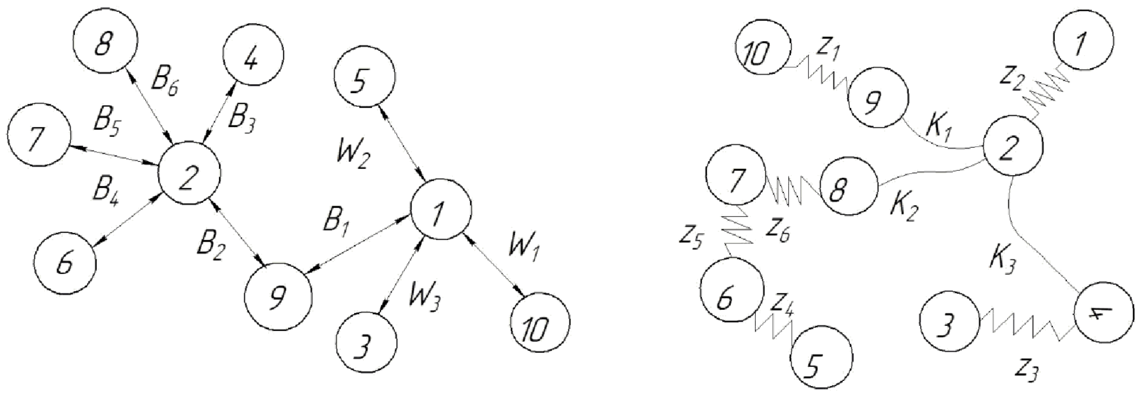


Figure 2.5 – Derivative and output graph trees.

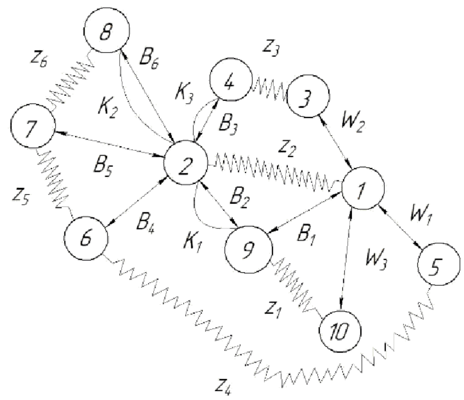


Figure 2.6 – Combined graph.

The correctness of the construction of each tree was checked according to the following criteria:

- the number of vertices in each tree is equal to the number of surfaces on the dimensional diagram of the technological process;

- the number of edges in each tree is equal to the number of vertices reduced by one;

- Each vertex of the derived tree, except the root, is approached by only one arrow of the directed edge, and none by the root vertex;

- a connected graph tree has closed loops..

2.1.5.3 Determination of intermediate minimum allowances for machining flat surfaces.

To carry out the necessary calculations in the future, it is necessary to determine the intermediate minimum allowances according to the reference book [17].

$Z_{3\,min} = 2$ mm; $Z_{4\,min} = 2$ mm;

$Z_{2\,min} = 2{,}1$ mm; $Z_{5\,min} = 1{,}2$ mm;

$Z_{1\,min} = 2$ mm. $Z_{6\,min} = 0{,}8$ mm;

Using graph trees, calculation equations were written to calculate the values of all dimensions, which are listed in Table 2.3.

Table 2.3 – Equations for calculating dimensional process chains

Calculation equation	Original equation	The size to be determined
$-K_3+B_3=0$	$K_3=B_3$	B_3
$-K_2+B_6=0$	$K_2=B_6$	B_6
$-K_1+B_2=0$	$K_1=B_2$	B_2
$Z_2+B_2-B_1=0$	$B_1=Z_2+B_2$	B_1
$Z_1+B_1-W_1=0$	$W_1=B_1+Z_1$	W_1
$B_5+Z_6-B_6=0$	$B_5=B_6-Z_6$	B_5
$B_4+Z_5-B_5=0$	$B_4=B_5-Z_5$	B_4
$Z_4-B_4+Z_2+W_2=0$	$Z_4=B_4-Z_2-W_2$	W_2
$Z_3-B_3+W_3+Z_2=0$	$Z_3=B_3-W_3-Z_2$	W_3

2.1.5.4 Determination of technological dimensions, dimensions of the initial workpiece, maximum allowances, correction (if necessary) of tolerances of technological dimensions and (or) machining route.

According to the above equations, we find the values of technological dimensions.

Here are the values of the design dimensions:

1. $К_3 = В_3 = 65\pm0.37$ mm.

2. $К_2 = В_6 = 69\pm0.3$ mm.

3. $К_1 = В_2 = 90\pm0.87$ mm.

4. $Z_{2\,min} = B_{1\,min} - B_{2\,max}$

$B_{1min} = B_{2\,max} + Z_{2min} = 90+2=92$ mm;

$B_{1\,max} = B_{1\,min} + T(B_1) = 92+0,87=92,87$ mm;

$Z_{2max} = B_{1max} - B_{2min}$

$Z_{2max} = 92,87-89,13=3,73$ mm.

Nominal value B_2:

$B_{1ном} = (B_{1min} + B_{1max})/2 = (92+92,87)/2 = 92,41$ mm.

5. $Z_{1min} = W_{1\,min} - B_{1\,max}$

$W_{1\,miп} = B_{1\,max} + Z_{1min} = 92,87+2=94,87$ mm;

$W_{1\,max} = W_{1\,miп} + T(W_1) = 94,87+1,4=108,87$ mm;

$Z_{1max} = W_{1max} - B_{1min}$

$Z_{1max} = 4,8$ mm.

Nominal value B_1:

$W_{1ном} = (W_{1min} + W_{1max})/2 = (94,87+108,87)/2 = 101,87$ mm.

6. $Z_{6\,min} = B_{6\,min} - B_{5\,max}$

$B_{6miп} = B_{5\,max} + Z_{6min} = 68,2+0,8=69$ mm;

$B_{6max} = B_{6miп} + T(B_6) = 69+0,3=69,3$ mm;

$Z_{6max} = B_{6max} - B_{5min}$

$Z_{6max} = 69,3-67,9=1,4$ mm.

Nominal value W_1:

$B_{5ном} = (B_{5min} + B_{5max})/2 = (68,2+69,3)/2 = 68,75$ mm.

7. $Z_{5\,min} = B_{5\,min} - B_{4\,max}$

$B_{5miп} = B_{4\,max} + Z_{5min} = 63+1.2=64.2$ mm;

$B_{5max} = B_{5miп} + T(B_5) = 64,2+0,074=62,27$ mm;

$Z_{5max} = B_{5max} - B_{4min}$

$Z_{5max} = 62,27-62,13=0,14$ mm.

Nominal value W_1:

$B_{4ном}$=(B_{4min}+ B_{4max})/2=(62,13+63)/2=62,56 mm.

Conclusions: Technological equations in most cases consist of 2–3 links. In general, the TP of mechanical processing is optimal.

2.1.6 Calculation of allowances and between-operation sizes

Determination of allowances and technological dimensions for surface machining ∅30H7($_{-0,021}$), Ra 1,6.

The workpiece is installed in the centers. The machining route: rough turning, finish turning, grinding. For external and internal surfaces, the minimum allowance is determined by the formula

$$2Z_{i\min} = 2\cdot\left(R_{Z_{i-1}} + T_{i-1} + \rho_{i-1}\right) \tag{2.1}$$

R_z – is the height of micro-roughnesses, μm;

T – depth of the defective layer, μm;

ρ - sum of spatial deviations, microns;

Total value of spatial deviations for stamped blanks

$$\rho_з = \sqrt{\rho_{cor}^2 + \rho_{zm}^2 + \rho_c^2} \tag{2.2}$$

where ρ_{cor} – the amount of warping of the workpiece [3]

$$\rho_{cor} = \Delta_к \cdot l = 0,8 \cdot 45 = 36\ \text{μm}.$$

Center deviations:

$$\rho_ц = \sqrt{(\frac{\delta_з}{2})^2 + 0,25^2} \tag{2.3}$$

$\delta_з = 3,0$ mm for M1 i C2

$$\rho_c = \sqrt{1,5^2 + 0,25^2} = 1,52\ mm$$

Thus, the total value of the spatial deviation of the workpiece:

$$\rho_z = \sqrt{0,4^2 + 0,04^2 + 0,025^2} = 1,571 = 157\ \mu m$$

Final spatial deviation after rough boring

after rough boring

$$\rho_1 = 0,06 \cdot \rho_з = 0,06 \cdot 1570 = 94,2\ \mu m$$

after final turning

$$\rho_2 = 0,04 \cdot \rho_з = 0,04 \cdot 1570 = 62,8\ \mu m$$

The calculation data are summarized in table 2.4.

Table 2.4 – Calculation of allowances and limit sizes for technological transitions for hole processing

Processing route	Elements of the assumption				Solution solutions.		add. µm	Accepted.		Grand value	
	R_z	T	ρ	E_i	$2Z_{min}$	d_p		d_{min}	d_{max}	Z_{max}	Z_{min}
Workpiece ∅33.6	150	200	1570	–	–	34,5	1000	34,5	35,5	–	–
Rough turning	50	50	94	-	$2 \cdot 1920$	30,658	160	30,66	30,82	4680	3840
Finish turning	30	30	63	-	$2 \cdot 194$	30,267	39	30,27	30,31	510	390
Grinding	10	20	–	-	$2 \cdot 123$	30,021	21	30,021	30,04	270	249

We calculate the minimum allowances:

- for rough boring

$$2Z_{1\min} = 2 \cdot (150 + 200 + 1570) = 2 \cdot 1920\ \mu m$$

- for fine boring

$$2Z_{2\min} = 2(50 + 50 + 94) = 2 \cdot 194\ \mu m$$

- for fine boring

$$2Z_{3\min} = 2(30+30+63) = 2\cdot 123 \ \mu m$$

We determine the calculated size d_P

$$d_p = 30{,}021+0{,}246 = 30{,}267 \approx 30{,}27 mm;$$

$$d_p = 30{,}27+0{,}388 = 30{,}658 \approx 30{,}66 mm;$$

$$d_p = 30{,}66+3{,}84 = 34{,}5 mm;$$

We calculate the largest technological dimensions using the formula

$$d_{\max i} = d_{\max i-1} + 2\cdot Z_{\min +1} \tag{2.4}$$

$$d_{\max 3} = 30{,}021 + 0{,}021 = 30{,}04 \text{ mm};$$

$$d_{\max 2} = 30{,}27 + 0{,}039 = 30{,}31 \text{ mm};$$

$$d_{\max 1} = 30{,}66 + 0{,}16 = 30{,}82 \text{ mm}.$$

$$d_{\max w} = 34{,}5 + 1 = 35{,}5 \text{ mm}.$$

We calculate the maximum allowances using the formula

$$2\cdot Z^{гр}_{\max i} = d_{\max i} - d_{\max i-1} \tag{2.5}$$

$$2\cdot Z^{гр}_{\max 3} = 30{,}31 - 30{,}04 = 0{,}27 \text{ mm=270мкм};$$

$$2\cdot Z^{гр}_{\max 2} = 30{,}82 - 30{,}31 = 0{,}51 \text{ mm=510мкм};$$

$$2\cdot Z^{гр}_{\max 1} = 35{,}5 - 30{,}82 = 4{,}68 \text{ mm=4680мкм}.$$

We calculate the minimum allowances using the formula

$$2\cdot Z^{гр}_{\min i} = d_{\min i} - d_{\min i-1} \tag{2.6}$$

$$2\cdot Z^{гр}_{\min 3} = 30{,}27 - 30{,}021 = 0{,}249 \text{ mm=249мкм};$$

$$2\cdot Z^{гр}_{\min 2} = 30{,}66 - 30{,}27 = 0{,}39 \text{ mm=390мкм};$$

$$2\cdot Z^{гр}_{\min 1} = 34{,}5 - 30{,}66 = 3{,}84 \text{ mm=3840мкм}$$

Audit:

$$2Z^{ep}_{\max i} - 2Z^{ep}_{\min i} = \delta_{i-1} - \delta_i \quad (2.7)$$

- rough boring

4.68 – 3.84 = 1 – 0.16;

0.84 = 0.84.

- fine boring

0.51 – 0.39= 0.16– 0.039;

0.12 = 0.12.

- fine boring

0.27 – 0.249 = 0.039 – 0.021;

0.02 = 0.02.

Determination of intermediate allowances according to standards and calculation of technological dimensions and maximum allowances for machining the remaining cylindrical surfaces.

Table 2.5 – Allowances for diametrical dimensions according to standards

Part size	Processing stage	Transition allowance	The resulting size
∅12H7	Drilling Pre-deployment Deployment final	2,0 0,7 0,3	14 12,07 12
M20-7g	Turning Thread cutting	 2	22 8

Other surfaces are processed in one pass.

2.1.7 Assignment of cutting modes (analytical calculation for three different types of processing, others are assigned according to standards)

Operation 020- Drilling, roughing and finishing of the hole.

Material-steel20X

Roughness -Ra=1.25

Machine model – 2R135F3

Depth of cut during rough reaming $t_н$ =0,21; correction factor $К_t$=2,4, t=0,21 $\cdot 2{,}4 = 0{,}54$; for finishing boring – t=0,10$\cdot 0{,}10 = 0{,}10$;

Choice of feed.

Drilling - D=10,8 mm; l/D=8,7; $S_{от}$=0,14mm/rev.

Rough reaming - D=11,9 mm;; $S_{от}$=0,71 mm/rev.

Finishing reaming - D= D т=12 mm; $S_{от}$=0,58mm/rev.

Drilling $S_о = S_{от} \cdot K_{SM}$; K_{SM}=1,1; $S_о$=0,14·1,1=0,154 mm/rev.

$$V = \frac{C_v D^{q_v}}{T^m t^{x_v} S^{y_v}} K_v = \frac{34.2 \cdot 10.8^{0,45}}{60^{0.23} 5{,}4^0 0{,}14^{0,3}} \cdot 0.888 = 23.81$$

C_v=34,2; x_v=0; y_v=0,3; m=0,3, q_v=0.45– coefficients and exponents in the formula for calculating cutting speed.

$$K_v = K_{Mv} \cdot K_{uv} \cdot K_{lv} = 1{,}07 \cdot 0{,}83 \cdot 1 = 0{,}888,$$

All components reflect the influence of a certain factor on the cutting speed: K_{Mv} = 1,07, K_{uv} =0,83, K_{lv} =1.

$$n = \frac{1000 \cdot V}{\pi \cdot D} \quad (2.8).$$

n= 701 rpm =710 rpm.

$S_M = S_о \cdot n$ = 98,2=100 mm/rev;

$$V_f = \frac{\pi \cdot D \cdot n_f}{1000} \quad (2.9)$$

V_f=24,07 м/min.

For the remaining transitions we calculate similarly (table 2.6).

Table 2.6 – Cutting modes for machining design bases and mounting holes

Operations, transitions	Cutting modes			
	S, mm/rev	n, rpm	V, m/min	t, mm
005 CNC turret lathe				
Trim end1 once	0.15	1000	195	2.0
Center hole 2	0.15	800	25	2.5
010 Vertical milling machine with CNC				
Mill end face 1 once	0.2	125	110	1.0
Center hole 2	0.15	800	25	2.5
015 CNC lathe				
Sharpen the surface 1, one.	0.39	800	260.8	1.0
Sharpen end 2 once	0.15	800	257.6	2.0
Sharpen air 3 previous.	0.2	400	224	1.2
Sharpen the surface 3 times.	0.4	500	342	0.8
Sharpen the end 4 times.	0.4	400	778	2
Sharpen the end 4 ends.	0.2	500	937	1.4
Sharpen the surface. 5 units.	0.3	800	185	2.0
Sharpen the surface. 6 units.	0.3	800	155	2.0
Grind chamfer 7	0.4	500	185	1.0
Cut the thread on the surface 1	1.5	92	612	1.5
020 Vertical drilling with CNC				
Mill surface 1 once	0.2	125	110	1.0
Center hole 2	0.15	800	25	2.5
Drill hole 2 once	0.35	800	24	30
Turn hole 2 in advance	0.8	125	14	0.8
Unfold hole 2 completely	0.6	180	20	0.6
025 Vertical milling machine with CNC				
Mill surfaces 1 and 2 first	0.15	125	110	1.0
Mill surfaces 1 and 2 completely	0.15	125	110	0.8

2.2 Analysis of the technological process of manufacturing a part and the design features of the product

To make a rational decision about improving the workplace by automating certain processes, it is necessary to determine which technological operation is most optimal for implementing the above-mentioned improvements.

After analyzing the technological process, it is possible to distinguish two operations that have the smallest number of transitions and, accordingly, the relative share of auxiliary time is higher. However, since basing the workpiece on operation 015 is performed more simply, this will facilitate the development of automated equipment for the machine tool and use less precise equipment and robotic equipment. That is why this operation was chosen for the implementation of automation [14-16].

2.3 Schematic diagram of an automated workplace

The layout of the workplace is an important stage of development, since the properties and characteristics of its components will depend on the principle by which its components will be arranged. In particular, robotic equipment. For our workplace, it is advisable to arrange an industrial robot so that it can service all the involved units of both the main and auxiliary equipment. For such purposes, the “ring” layout is best suited (Fig. 2.7).

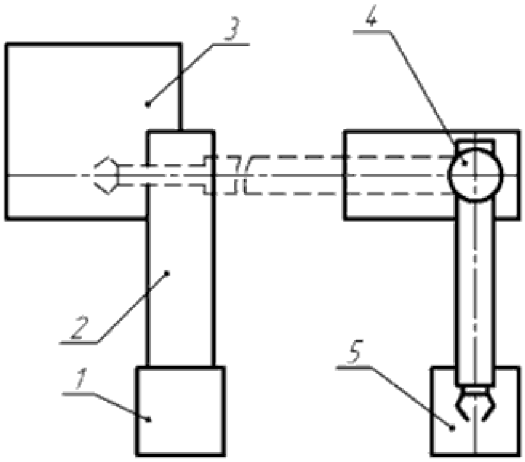


Figure 2.7 – Diagram of an automated workplace
1, 2 - equipment for feeding workpieces, 3 - main equipment, 4 - robot, 5 - auxiliary equipment

2.4 Conclusions to the chapter

1. A technological process for the mechanical machining of the "Support" part blank has been developed.

2. A dimensional analysis of the technological process was conducted, and machining allowances for the hole and cutting modes were calculated.

3. Performing dimensional analysis made it possible to determine the technological dimensions and the workpiece dimensions.

4. Based on the analysis of the feasibility of automation, operation 015 was selected, as automation in this case can reduce auxiliary time losses.

3 ALGORITHM OF THE AUTOMATED WORKSTATION FOR MECHANICAL PROCESSING OF SUPPORT PARTS IN CNC MILLING OPERATIONS

3.1 Algorithm of operation of the automated workstation for machining of the Support part in the milling operation with CNC

Since the processing process at the workplace must be fully automated, it is necessary to develop a sequence of actions of the workplace elements to perform the necessary transitions and actions during the processing process (Table 3.1) [11].

Table 3.1 - Algorithm of operation of an automated workplace

Type of work	Technological element
Preparation of the workpiece for feeding, installation in auxiliary equipment	Equipment for pre-orientation of workpieces, also the installation can be performed by a worker for one shift or more.
Taking the workpiece with the manipulator	Industrial robot
Installing the workpiece on the machine tool	Industrial robot Developed machine tool equipment
Processing the workpiece on the machine tool	Machine tool, developed machine tool equipment
Removing the workpiece from the machine	Industrial robot Machine tools
Moving the workpiece to the assembly location of finished parts	Industrial robot
Changing elements of an automated place to prepare for the execution of the next workpiece	Clock table

3.2 Conclusions to the chapter

1. A list of actions and equipment for their implementation during automated operation of an automated workplace has been determined.
2. A general algorithm for the operation of an automated workplace for the technological processing of the “Support” part has been developed.

4 AUTOMATION OF PRODUCTION ELEMENTS

4.1 Selection of basic equipment

The main part of the automated workplace is technological equipment (metal-cutting machines, presses, heating furnaces, etc.), since its operation ensures the production of products [14-15].

Equipment for the workplace should have an automated work cycle, product clamping, as well as devices for automatic tool change, etc. However, this is not always possible in production, since automatic machines are not widespread enough.

For the "Support" part, the 6R13RF3 model machine fully meets the specified requirements.

The 6R13RF3 model machines are designed for multi-operation processing of parts of complex configuration made of steel, cast iron, non-ferrous and light metals, as well as other materials. Along with milling operations, the machines can perform precise drilling, boring, countersinking and reaming of holes

Main parameters of the machine:

machine accuracy class - H;

length of the working surface of the table, mm - 1600;

table width, mm – 400;

table movement X,Y,Z, mm – 1000, 400, 380;

machine dimensions (length, width, height (mm)) – 3200, 2500, 2450;

weight, kg – 6900;

engine power, kW – 7.5;

spindle speed limits min/max rpm – 40/3000;

number of tools in the store, pcs – 8.

4.2 Choosing an industrial robot (IR) for an workstation

The main requirements that an industrial robot must meet are as follows [21-22]:

- ensuring the specified load capacity;

- the dimensions of the working area of an industrial robot should be determined by the dimensions, shape and position of the working areas of the equipment being serviced;

-the control system of an industrial robot is selected taking into account the method of positioning the working body, the number of control coordinates, and the amount of memory;

-the gripping device (GD) is selected taking into account the structural and technological parameters of the object being manipulated.

- the load capacity of an industrial robot must exceed the mass of the manipulated object by at least 10%.

The shape and dimensions of the working area must be such that loading and unloading of the workpiece from the working area of the main and auxiliary equipment is carried out without hindrance.

For an industrial robot operating as part of an RTC, the number of degrees of freedom depends to the greatest extent on the shape, size, and position of the equipment's working area and the relative position of the limiting surfaces creating the loading-unloading area.

Positioning error significantly affects the process of installing the workpiece in the fixture, both the main and auxiliary equipment.

To service the workplace and technological equipment in accordance with the recommendations, an industrial robot of the “Universal” model was selected.5.02” (fig. 4.1), with the following characteristics:

-load capacity –5 kg;

-number of mobility stages – 6;

-number of hands -1;

-number of gripping devices on one arm - 1;

-drive of the main movements - electric;

-control system - positional;

-number of programmable coordinates- 4;

-programming tool for movement-training;

-system memory capacity, number of steps - 50;

-positioning error - ±1.0 mm;

-the greatest arm reach –1300 mm;

-linear displacement, mm/speed, m/s:

r = 700/0.9;

z = 400/0.3;

-angular displacements, °/ angular velocity, °/s:

φ =330/60;

α =180/180;

β =180/90;

-weight, kg- 650.

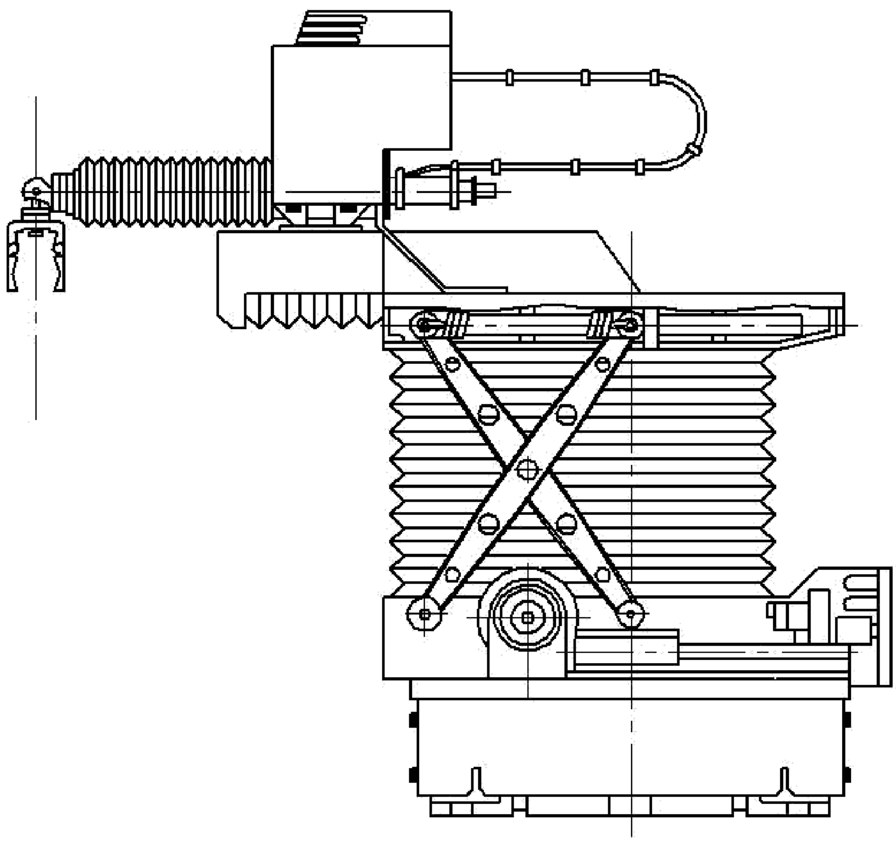


Figure 4.1 – IR scheme

4.3 Design (selection) of a gripping device

According to the machining route and part drawing, the workpiece will be based on a machine tool fixture on an external cylindrical surface Ø48h8. The most rational method is to install it on a prism and a side stop.

Therefore, we use these same surfaces to install the workpiece in the gripping device of the device (Fig. 4.2).

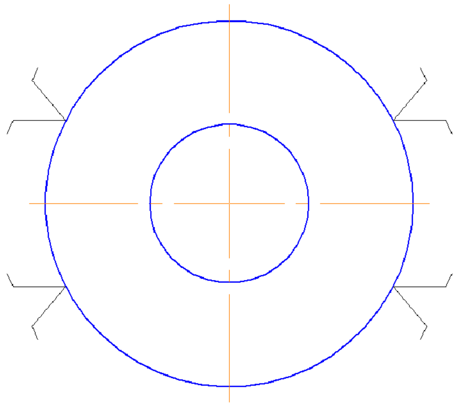


Figure 4.2 - Workpiece clamping diagram

4.3.1 Calculation of clamping forces of the gripping body of an industrial robot

The gripping force is determined from the assumption that the holding of the manipulated object occurs due to the frictional forces created by this force:

$$F = K1 \cdot K2 \cdot K3 \cdot m \cdot g, \text{ [H]} \tag{4.1}$$

where m is the mass of the manipulated object (mass of the workpiece);

g – acceleration of free fall;

K1 – safety factor, K1=1.2 – 2.0. We assume K1=1.2;

K2 is a coefficient depending on the maximum acceleration A with which the robot moves an object fixed in the gripping device. For pneumatic robots $A \approx g$. K2=1+A/g=1.8;

K3 – transmission coefficient, depending on the design of the grip and the location of the manipulated object in it, is selected according to [4].

$$K_3 = \frac{\sin\theta}{2\mu}, \tag{4.2}$$

where θ is half the angle of inclination of the jaws of the gripper θ = 60˚.

μ- coefficient of friction between the object being manipulated and the jaws. μ=0.15

$$K_3 = \frac{\sin 60°}{2\cdot 0{,}15} = 2{,}9.$$

F= 1.2·1.8·2.9·0.8·9.8 = 47.8 (N).

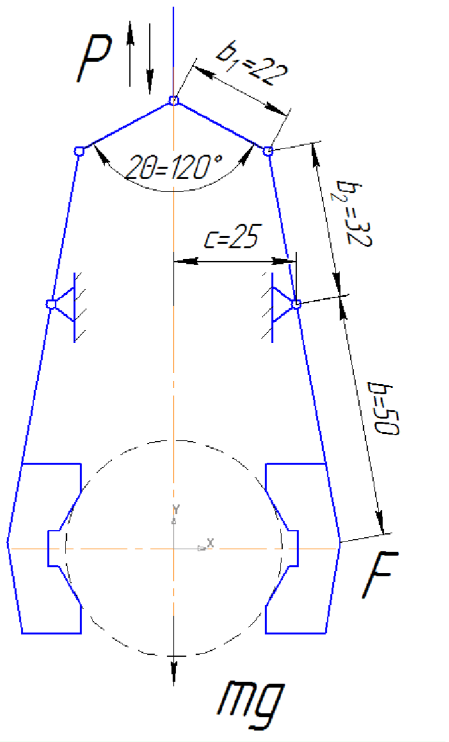


Figure 4.3 – Scheme of the gripping device

According to [4], the equation of equilibrium of clamping forces is as follows:

$$b \cdot F = \left[tg\Theta \sqrt{1 - \left(\frac{b_1 \sin \Theta - c}{b} \right)^2} - \frac{b_1 \sin \Theta - c}{b} \right] \cdot \frac{P}{2} \cdot b_2, \qquad (4.3)$$

where

$$P = \frac{2 \cdot b \cdot F}{\left[tg\Theta \sqrt{1 - \left(\frac{b_1 \sin \Theta - c}{b} \right)^2} - \frac{b_1 \sin \Theta - c}{b} \right] \cdot b_2} . [N] \qquad (4.4)$$

When designing the GD, we assume b=0.05m, b1=0.022m, b2=0.032m, c=0.025m, angle θ=60˚.

$$P = \frac{2 \cdot 0{,}05 \cdot 47.8}{\left[tg60 \sqrt{1 - \left(\frac{0{,}022 \sin 60 - 0{,}025}{0{,}05} \right)^2} - \frac{0{,}022 \sin 60 - 0{,}025}{0{,}05} \right] \cdot 0{,}032} = 82(H).$$

Determine the piston diameter

For single-acting cylinder [4]

$$F = p_в \cdot \frac{\pi \cdot D^2}{4} - F_T - F_P, \text{ [mm]} \qquad (4.5)$$

$$D = \sqrt{\frac{4 \cdot (F + F_T + F_P)}{\pi \cdot p_в}} = \sqrt{\frac{4 \cdot (82 + 8 + 8)}{\pi \cdot 0.6 \cdot 10^6}} = 14.4 \cdot 10^{-3} (м)$$

Therefore, to ensure clamping of the part, a pneumatic cylinder with a working diameter larger than14.4 mm, we take the nearest standard piston diameter D=15 mm.

4.4 Analysis of part positioning accuracy

Let us consider the errors that arise during automatic installation of the workpiece on the machine (Figure 4.4).

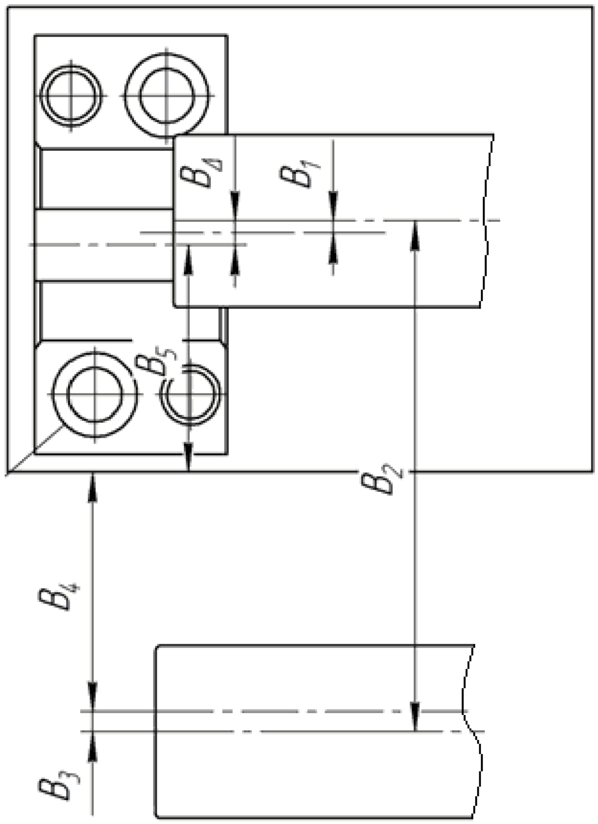


Figure 4.4 – Dimensional relationship diagram

VΔ- deviation from the coaxial prism of the clamping device of the machine and the axis of the loaded workpiece

B1 – deviation from the coaxial workpiece in the GD.

B2 – deviations resulting from IR inaccuracy.

B3 – deviation that may occur as a result of inaccurate positioning of the workpiece in the workpiece feeder.

B4 – distance between the machine tool and the robot.

B5 – distance from the axis of the machine tool clamping device to the main base of the machine tool.

The robot takes the workpiece into the fixture and removes the part. The robot takes the workpiece with a gripping device, brings it into the working area of the machine so that the axis of the workpiece coincides with the axis of the mandrel, then installs the workpiece on the mandrel, after which a command is given to clamp the fixture.

To facilitate the installation process, a guide cone is made on the front of the mandrel. Installation of the workpiece on the mandrel is possible if B does not exceed the value:

$$Vmax = \frac{D-d}{2 \cdot K_3}, \qquad [mm] \qquad (4.6)$$

where D – Installation size of the prism;

d – outer diameter of the Bushing;

K_3 – safety factor (K_3 = 1.1-1.2).

$$Vmax = \frac{60-45}{2 \cdot 1{,}1} = 6.81 (mm),$$

B2 =±1.0 mm

B1 =±0.5 mm

B3 = $30_{-0.021}$mm

B4 = 1100 –2.6 mm

B5 = 200 –1.15 mm

TΔ/ 2 = 2.0+1.0+0.021+2.6+1.15;

TΔ=6.771 mm.

Since TΔ≤ Bmax, therefore the accuracy is sufficient to perform the necessary operations.

4.5 Construction and calculation of the trajectory of movement of IR elements

The procedure for the robot is given in table 4.1

Table 4.1 – Elements of the trajectory of movement of the gripping device

Trajectory element	Comment	Displacement, mm(degrees)
r0 1	Moving the right hand forward	500
	Workpiece clamp	-
z1 2	Moving the right hand up	200
r2 3	Moving the left hand back	500
φ3 4	Turn the left hand clockwise	90°
r4 5	Moving the right hand forward	500
z5 6	Moving the left hand down	200
	Blanking of the workpiece	-
r6 7	Moving the left hand back	500
	Hands up IR	-
r7 8	Moving the right hand forward	500
	Workpiece clamp	-
z8 9	Moving the right hand up	200
r910	Moving the left hand back	500
φ 1011	Turn the left hand clockwise	90°
r1112	Moving the right hand forward	500
z1213	Moving the left hand down	200
	Blanking of the workpiece	-
r1314	Moving the left hand back	500
φ 1415	Hand rotation against the left hand counterclockwise	180°

Let us present in Figure 4.5 fragments of the trajectory of the IR movement.

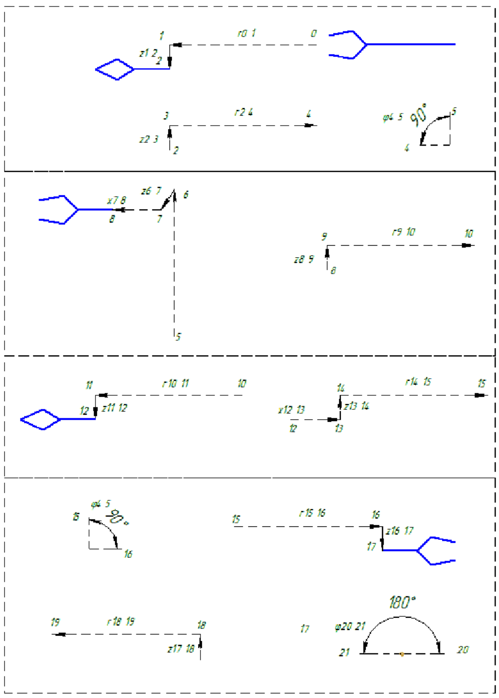


Figure 4.5 - Fragments of the trajectory of the PR movement

4.6 Selection of auxiliary equipment for the workstation

The main functions of auxiliary equipment are:

-accumulation function;

-function of transportation and individual product delivery;

-product orientation and reorientation function.

The complexity of the tasks performed requires the use of various auxiliary devices.

The main requirement for selecting auxiliary equipment for RTC is: the workpiece during entry and removal must occupy the required position relative to the gripping device of the IR, and the working area of the auxiliary equipment must intersect with the working area of the industrial robot.

Based on the fact that the part has a cylindrical shape, a small mass, and relatively small dimensions, we choose tray magazines as the transport and storage device.

Trays are transport devices that serve to direct the movement of parts along a given trajectory to a given point in the working space of the equipment. At the same time, trays perform the functions of accumulators that ensure the uninterrupted operation of technological equipment.

4.7 Analysis of possible workstation layout options

For our workplace, we choose a ring layout scheme. In the ring layout, the equipment is located directly around the robot. The ring layout of the RTC provides convenience for loading and unloading equipment, unhindered movement of the IR gripping device. It provides a reduction in auxiliary time for securing and installing the workpiece, which allows you to reduce the manual - calculation time and, therefore, increase productivity (Fig. 4.6.).

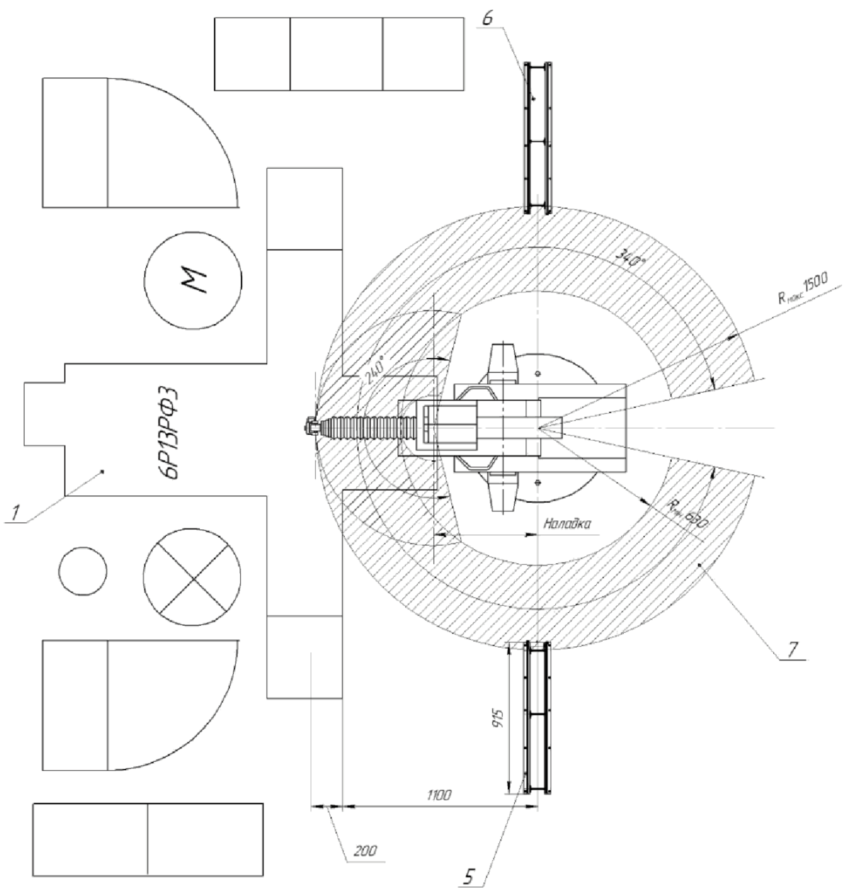


Figure 4.6 - Ring type circuit diagram

4.8 Calculation of workpiece movement speeds

To determine the linear positioning speed in the range of the industrial robot arm, we will use the formula:

$$V_X = \frac{2 \cdot L_X \cdot \sqrt[4]{\Delta l}}{\sqrt[3]{M}}, \text{[m/s]} \qquad (4.7)$$

where L_X - IR arm extension;

Δl - positioning error;

M - mass of the object being manipulated (mass of the workpiece, parts), m_{total} =0.7 kg, m_{de}t. =4.47 kg. We perform calculations based on the largest mass.

$$V_X = \frac{2 \cdot 0{,}5 \cdot \sqrt[4]{2}}{\sqrt[3]{0.7}} = 1.34 (м/с).$$

The vertical displacement speed of the IR, provided that the masses are balanced, is found by the formula:

$$V_Z = \frac{\alpha_Z \cdot \sqrt{L_Z} \cdot \sqrt[4]{\Delta l}}{\sqrt[3]{M}}, \text{[m/s]} \quad (4.8)$$

where α_Z - coefficient depends on the drive design, α_Z=3;

L_X - path length during vertical movement, m;

M is the mass of the manipulated object;

$$V_Z = \frac{3 \cdot \sqrt{0,2} \cdot \sqrt[4]{2}}{\sqrt[3]{0.7}} = 1.8(м/c).$$

Angular velocity when turning the IR arm relative to the vertical axis:

$$\omega = \frac{0,5\sqrt{\varphi} \cdot \sqrt[4]{\delta}}{\sqrt[3]{(2L_x)^4}}, \text{[rad/s]} \quad (4.9)$$

where δ is the angular positioning error, s

φ – arm rotation angle, rad.;

$$\delta = \frac{\Delta l}{L_r} \cdot \frac{180}{\pi} = \frac{2}{0.5} \cdot \frac{180}{\pi} = 573.$$

$$\omega = \frac{0,5\sqrt{3.14} \cdot \sqrt[4]{573}}{\sqrt[3]{(2 \cdot 0,5)^4}} = 4,33(radc).$$

The part under consideration has a small weight and therefore can be moved at fairly high speeds, however, the values found exceed the technical capabilities of the IR, therefore, for further calculations, we will use the data of the technical characteristics of the IR, namely:

-linear movements:

r – 0.9 m/s;

z –0.3 m/s;

-angular displacements:

φ =60°/s.

4.9 Development of a cycle diagram for the functioning of the workstation

The cycle diagram of the RTC operation includes, in the selected sequence, all actions performed by the main and auxiliary equipment, as well as the IR necessary for processing the workpiece.

The construction of a cyclogram of the functioning of the RTC provides a quick determination of the operating cycle Tr, the value of the cycle productivity Qc. The construction of the cyclogram also gives a significant idea of how it is possible to reduce Tr by combining the execution time of individual transitions and reducing the duration of non-aligned transitions.

After we have identified all the IR movements and established the sequence of their execution, we need to determine the execution time of each movement using the following formulas:

$$t_I = \frac{\phi_I}{\omega_I}; \text{ [c]} \tag{4.10}$$

$$t_I = \frac{l_I}{V_I}, \text{ [c]} \tag{4.11}$$

where ϕ_I- angles of rotation of mechanisms;

l_I- linear movements of mechanisms;

$\omega_I V_I$- angular and linear movement speeds of mechanisms along the corresponding coordinate.

Taking into account definitions 4.7-4.9, we will conduct a study of the influence of the parameters of the robot manipulator on its speed and other characteristics.

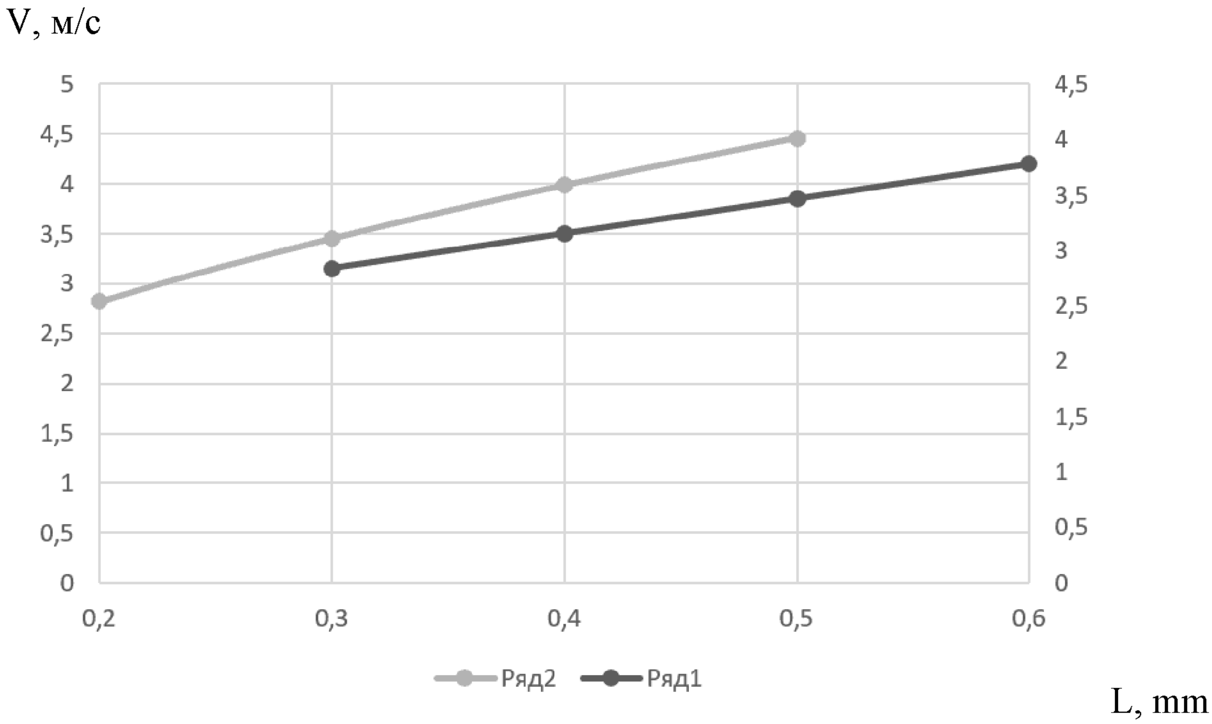


Figure 4.7 – Dependence of the speed of movement along the X and Z axes on the maximum departure

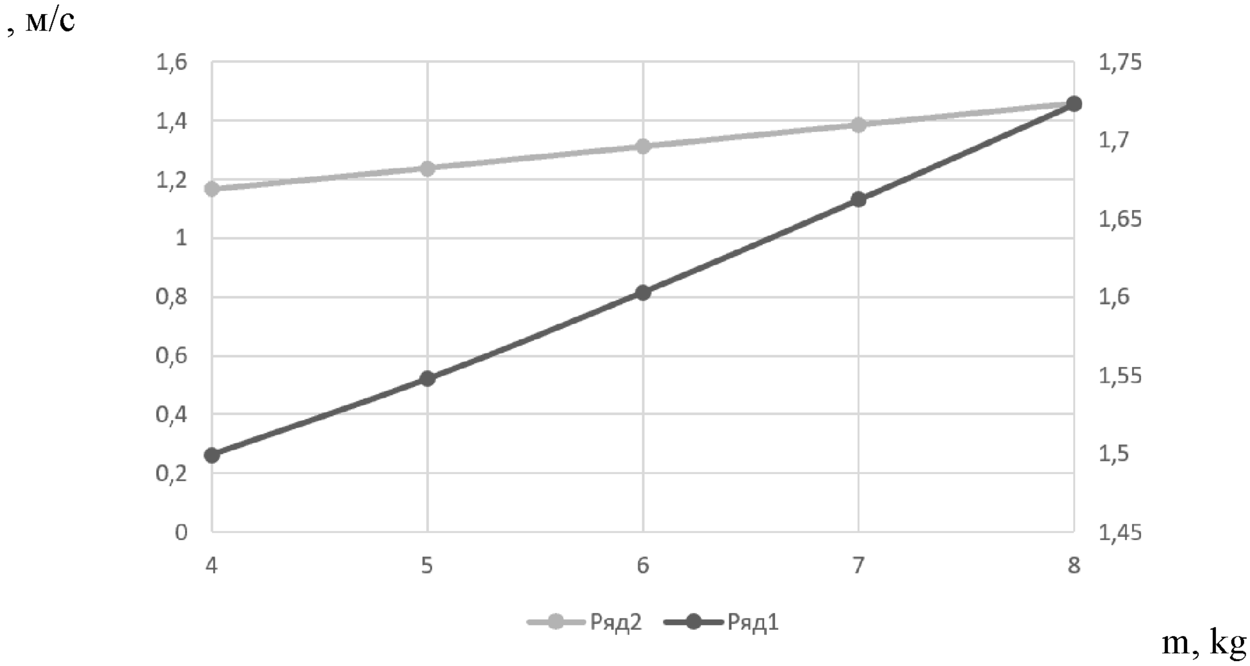


Figure 4.8 – Dependence of the speed of movement along the X and Z axes on the mass

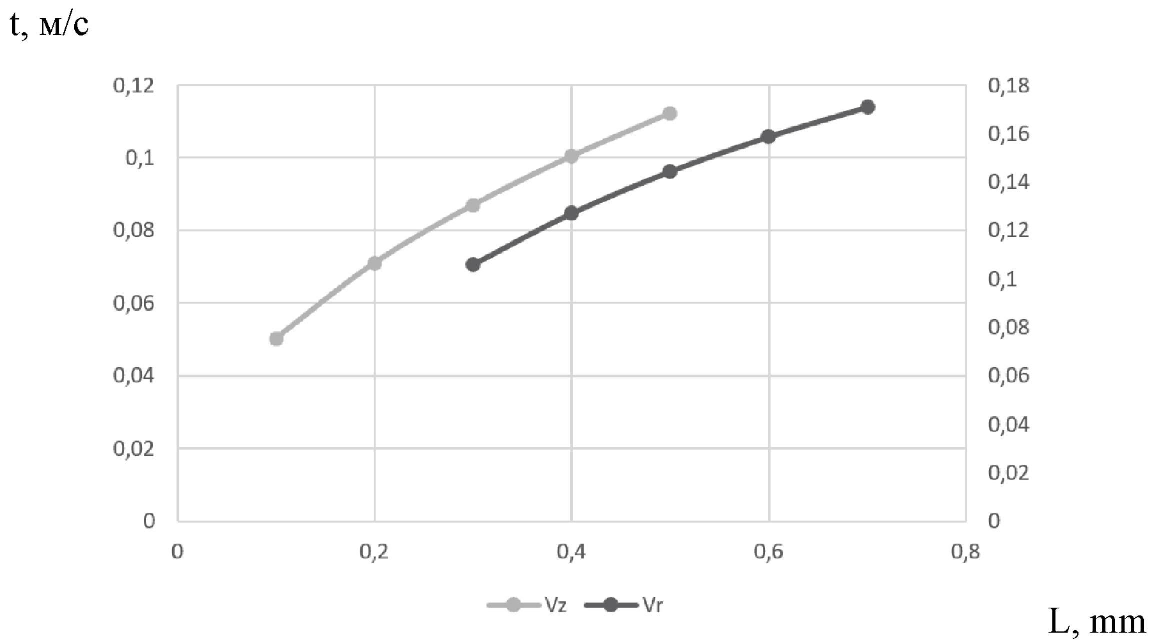


Figure 4.9 – Dependence of movement time along the X and Z axes on the maximum departure

Based on the analysis of the graphs presented in Fig. 4.7-4.9, it can be concluded that an increase in the manipulator travel results in an increase in linear speeds, which can be considered a positive factor, however, this increase also leads to a deterioration in the time characteristics of the operation.

A flow chart is a graphic representation of the sequence of operation of individual elements and subsystems (Fig. 4.10).

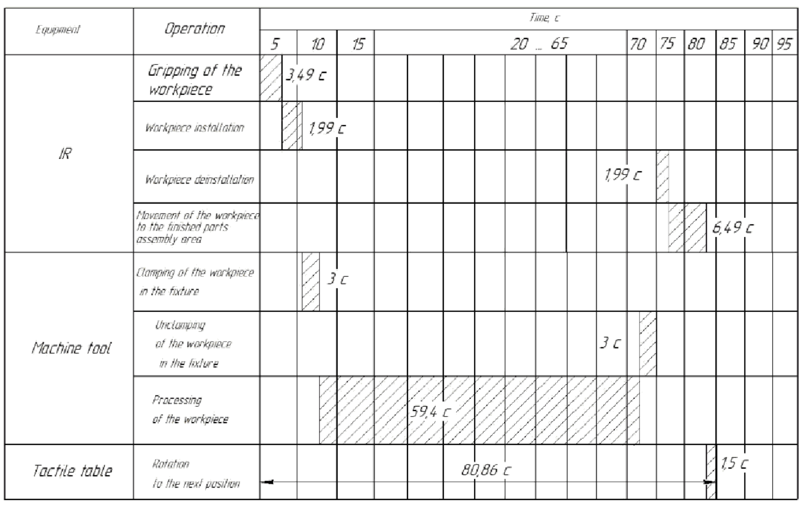


Figure 4.10 – RTC operation flow chart

4.10 Created of machining program for a CNC machine

For example lets show creating of program for CNC for lathe machine-tool. First need to open 3d model of a part (fig. 4.11).

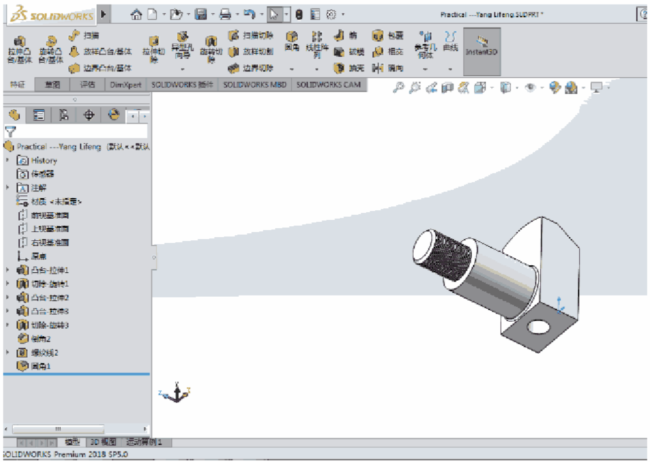


Figure 4.11 – Open the part to be processed

Next step is enter the machine tool settings, and select CNC lathe (fig. 4.12)

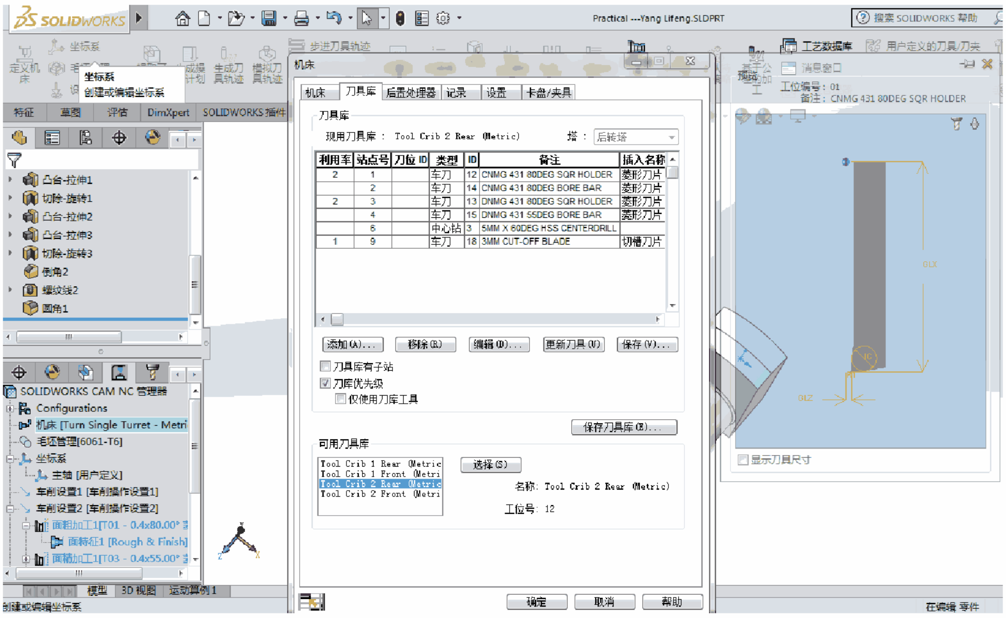


Figure 4.12 – Tool selection and settings

After that we need to set coordinate system settings and perform blank settings (fig. 4.13)

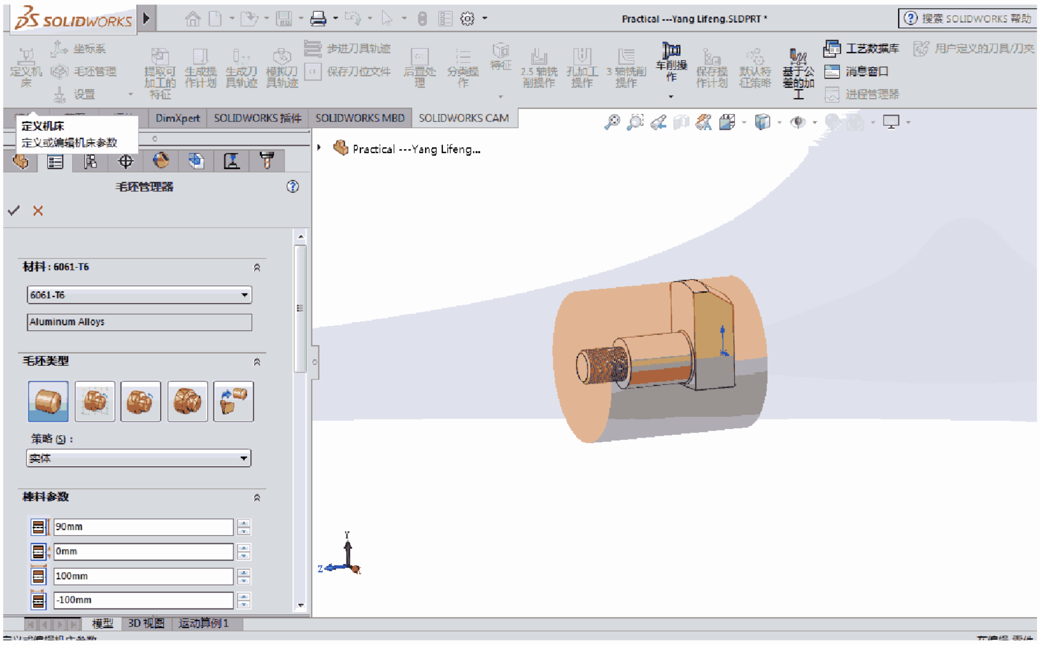


Figure 4.13 – Select blank management and perform blank settings

Next we need to select turning settings and add production operation plan (fig. 4.14)

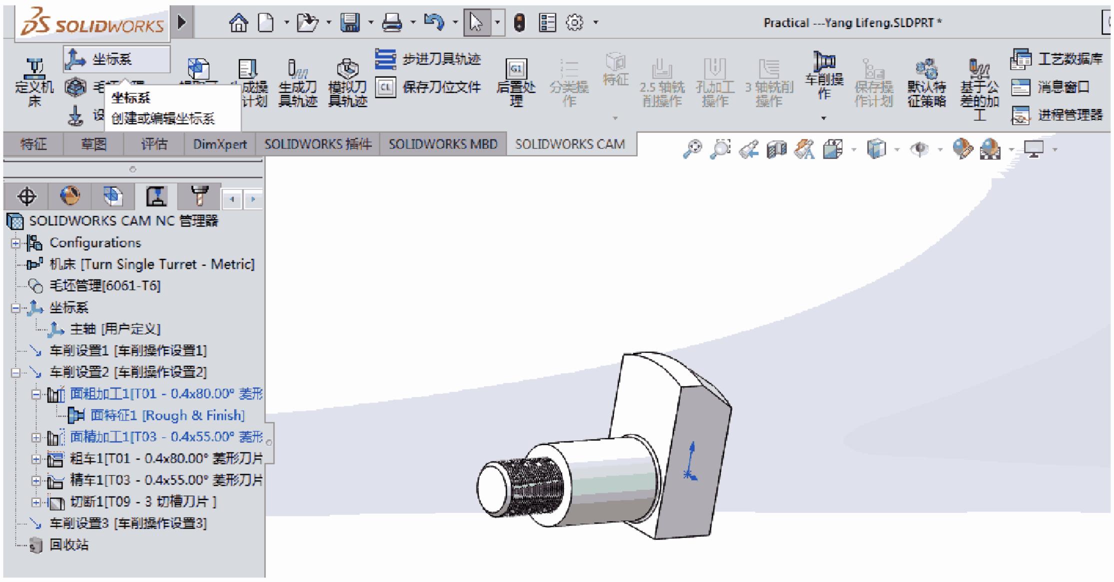


Figure 4.14 – Generate tool path

After all element of operation plan will be put in we can simulate the work of CNC machine-tool and save the program. (fig. 4.15)

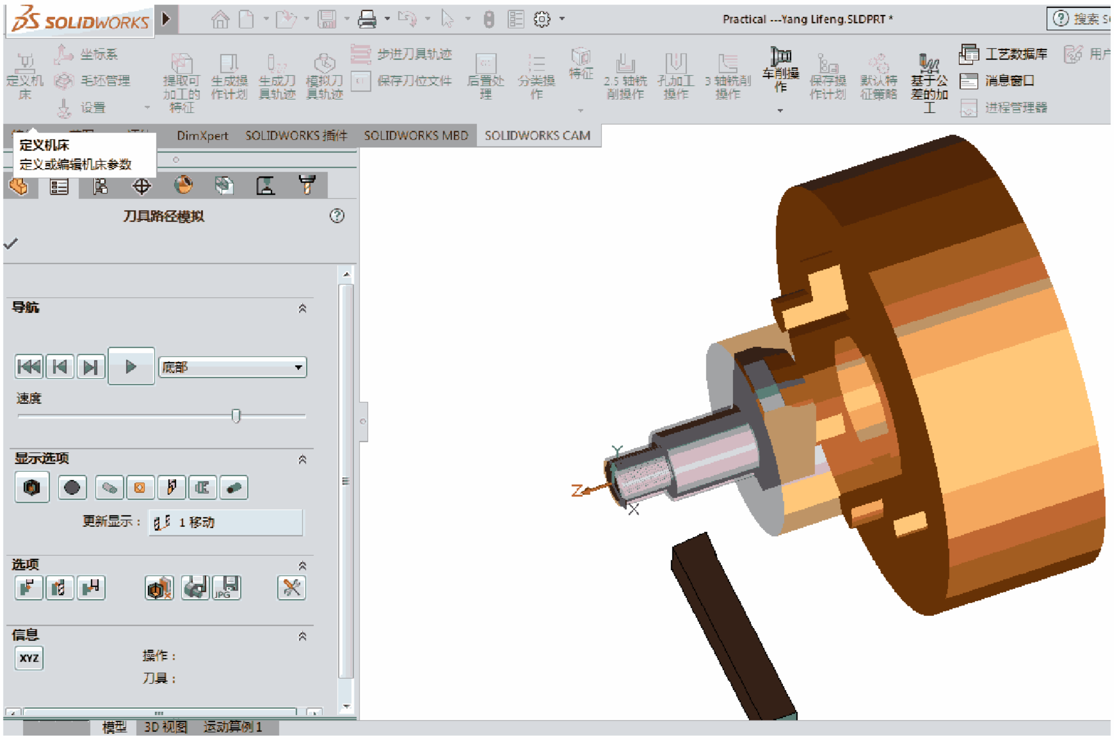


Figure 4.15 – simulate tool path

4.11 Determination of the main indicators of the workstation

The main indicators characterizing the operation of the RTC are the following: cycle productivity Qc; relative load factor of the IR Kgr; utilization factor of the IR Kvr; utilization factor of the main equipment Kvo; utilization factor of the IR Kzv; operating mode of the robot.

The cycle productivity is determined by the following formula:

$$Q_c = \frac{1}{T_P}; \qquad (4.12)$$

where T_P - duration of the work cycle, $T_P = 80.86$ s;

$$Q_c = \frac{1}{80{,}86} = 0{,}012(s);$$

Relative load factor K_l

$$K_l = \frac{P_{aw}}{P}; \qquad (4.13)$$

where P_{aw}- average workload, 0.7 kg;

P - robot load capacity, P=5 kg;

$$K_{ГР} = \frac{0,7}{5} = 0,14.$$

Coefficient of utilization Ku

$$K_u = \frac{T_{IR}}{T_c}; \qquad (4.14)$$

where T_{IR}- IR operating time per work cycle, 13.96 s;

$$K_u = \frac{13,96}{80.86} = 0,17;$$

Core equipment utilization rate $К_{ur}$

$$К_{ur} = \frac{T_O}{T_P}; \qquad (4.15)$$

where T_O- operating time of the main equipment per operating cycle, T_O= 65.4 s;

$$К_{ur} = \frac{64.4}{80,86} = 0,86.$$

4.12 Conclusions to the section

A machining program for a CNC machine was created using the SolidCAM system.

A list of actions and the equipment required to perform them in an automated workstation was determined.

A general algorithm for the operation of the automated workstation for machining the “Support" part has been developed.

The "Universal" industrial robot model was selected for use in the automated workstation.

A gripper device scheme was selected for handling the "Support" part.

Time expenditures were calculated, and dependencies of the robot’s speed and time characteristics on the manipulator's features and the mass of the handled load were studied.

The parameters of the workstation’s operation were defined. The total cycle time is 81 seconds.

5 ECONOMIC PART

5.1 Conducting a scientific audit of research work

For scientific and exploratory research, an assessment of the scientific effect is usually carried out.

The main features of the scientific effect of research work are the novelty of the work, the level of its theoretical elaboration, the prospects, the level of dissemination of results, and the possibility of implementation. The scientific effect of research can be characterized by two indicators: the degree of scientific novelty and the level of theoretical elaboration.

The values of the indicators of the degree of novelty and the level of theoretical elaboration of the research work in points are given in Tables 5.1 and 5.2.

Table 5.1 – Indicators of the degree of novelty of research work

Degree of novelty	Characteristics of the degree of novelty	Value of the degree of novelty indicator, points
1	2	3
Fundamentally new	The work is qualitatively new in terms of the problem statement and is based on the application of original research methods. The research results open a new direction in this field of science and technology. Fundamentally new facts and patterns have been obtained; a new theory has been developed. A fundamentally new device, method, and method have been created.	60…100
New	New information has been obtained that significantly reduces the uncertainty of existing values (known facts and patterns have been explained in a new or first way, new concepts have been introduced, the structure of the content has been revealed). Significant improvement, addition and clarification of previously achieved results have been carried out	40…60
Relatively new	The work has elements of novelty in the formulation of the problem and research methods. The results of the study systematize and generalize the available information, determine the paths of further research; for the first time a connection is found	10…40

Continuation of table 5.1

1	2	3
Relatively new	(or a new connection is found) between phenomena. In principle, known provisions are extended to a large number of objects, as a result of which an effective solution is found. Simpler methods are developed to achieve known results. Partial rational modification (with signs of novelty) is carried out	10…40
Traditional	The work was carried out using traditional methods. The research results are informative in nature. Known facts and statements that require verification are confirmed or questioned. A new solution has been found that does not provide significant advantages compared to the existing one.	2…10
Not new	A result was obtained that was previously recorded in the information field and was not known to the authors.	1…2

Table 5.2 – Indicators of the level of theoretical elaboration of research work

Characteristics of the level of theoretical elaboration	Value of the indicator of the level of theoretical elaboration, points
Discovery of the law, development of the theory	80…100
Deep study of the problem: multi-faceted analysis of connections, interdependence between facts with the presence of explanations, scientific systematization with the construction of a heuristic model or a complex forecast	60…80
Development of a method (algorithm, program), device, obtaining a new substance	20…60
Elementary analysis of the connections between facts and the existing hypothesis, classification, practical recommendations for a particular case, etc.	6…20
Description of individual elementary facts, presentation of experience, results of observations, measurements, etc.	1…5

The indicator that characterizes the scientific effect is determined by the formula:

$$E_{sc} = 0{,}6 \cdot k_{new} + 0{,}4 \cdot k_{theor}, \quad (5.1)$$

where k_{new}, k_{theor}– indicators of the degree of novelty and the level of theoretical elaboration of the research work, points;

0.6 and 0.4 – the specific weight (significance) of the indicators of the degree of novelty and the level of theoretical elaboration of the research work.

The work proposes a scheme of an automated workplace for processing a workpiece = 20. Formula dependencies are used to calculate the speed of performing auxiliary operations by the robot based on empirical dependencies, therefore =15. Then the indicator characterizing the scientific effect is equal to:$k_{нов} k_{теор}$

$$E_{sc} = 0{,}6 \cdot 20 + 0{,}4 \cdot 15 = 19.5.$$

5.2 Forecasting the cost of performing the work

Calculation of the basic salary of developers.

The basic salary of developers, which is calculated according to the formula [27, 28]:

$$S_m = \frac{M}{T} \cdot t[\text{CU}], \quad (5.2)$$

where: M – monthly salary of each developer (researcher), in CU.

T– the number of working days in a month. Approximately T = 21 ÷ 22,

t– number of days of developer work.

For a project manager, the basic salary will be:

$$S_m = \frac{3000}{22} \cdot 21 = 2863(\text{CU}).$$

We calculate the salaries of other developers in a similar way. It is necessary to take into account that the most part of the work is performed by the process engineer.

Table 5.3 – Results of basic salary calculations

No. n/a	Job title	Monthly salary, CU	Payment per working day, CU	Numeric days works	Salary expenses, CU
1.	Project Manager	2863	136	21	2863
2.	Debugging engineer	2000	91	22	2000
3.	Operative	2000	91	22	2000
4.	Locksmith	2000	91	22	2000
Total					8863

The costs of basic wages of workers (Sw) are calculated based on the time standards required to perform technological operations to manufacture one product:

$$S_w = \sum_{i=0}^{n} t_i \cdot C_i \cdot K_c, \text{[CU]}, \qquad (5.3)$$

where: ti – time rate (labor intensity) for performing a technological operation, hours;

n– number of works by types and categories;

Ks– the coefficient of correlations, which is currently established by the General Tariff Agreement between the Government and trade unions. Ks=1 ÷ 5. We assume Ks =1.37;

Si– hourly tariff rate of a worker of the corresponding category who performs the corresponding technological operation, CU/h. C is determined by the formula:

$$C_i = \frac{M_m \cdot K_i}{T_w \cdot T_{sh}}, \text{[CU/hour]}, \qquad (5.4)$$

where: Mm – minimum monthly wage, CU. From 04/01/2024 – Mm = 200 CU;

K_i –tariff coefficient of a worker of the corresponding category and profession;

T_w –number of working days in a month. Approximately Tw = 21 ÷ 22;

T_{sh} – shift duration, T_{sh} = 8 hours.

Considering that workers of the fourth and fifth categories will have to work, the hourly wage rate will be:

$$C4 = 200 \cdot 1.5 \cdot 1.37 / (22 \cdot 8) = 2.22 \text{ (CU/hour)};$$

Table 5.4 – Basic salary costs

Equipment	Labor intensity hours	Work load	Hourly rate	Amount of payment, CU
Work on the arrangement of elements	130	4	2.22	290
Machine operator jobs	140	4	2.22	311
Locksmith work	80	4	2.22	178
Debugger's work	95	4	2.22	211
Total				990

Additional salary is calculated as 12% of the developers' base salary:

$$S_{add} = (8863+990) \cdot 12\% = 1182 \text{ (CU)}.$$

Wage accruals amounted to 22% of the sum of the basic and auxiliary wages:

$$(8863+990+1182) \cdot 0.22 = 2428 \text{ (CU)}.$$

Depreciation of equipment used in the manufacture of the device.

In a simplified form, depreciation deductions in general can be calculated using the formula:

$$A = \frac{P}{T_n} \frac{T_f}{12}, \quad (5.5)$$

where P is the book value of the equipment, CU;

T_f – useful life of the equipment (months);

Tn – standard period of use of equipment, years.

Table 5.5 – Results of depreciation calculations

Equipment name	Carrying amount, CU	Term of normative use, year.	Useful life, months.	Amount of depreciation deductions, CU.
Computer equipment	714	4	12	179
Industrial robot	6905	7	12	986
Locksmith equipment	3095	4	1	64
Equipment for layout and configuration	5119	6	1	71
Equipment for calculations	952	4	1	20

In accordance:

$$A = 179 + 986 + 64 + 71 + 20 = 1320\ (CU).$$

Material costs are calculated for each type of material using the formula:

$$M = \sum_{1}^{n} H_i \cdot P_i \cdot K_i - \sum_{1}^{n} B_i \cdot P_в \quad [CU] \qquad (5.6)$$

where: Hi – consumption of material of the i-th name, kg

Pi– cost of the material of the i-th name, CU/kg,

K_i – transportation cost coefficient, Ki = 1.1.

B_i – mass of waste of the i-th type,

$P_в$ – the price of waste of the i-th type,

n – number of types of materials.

The amount of waste in our case is the same for both production methods, so we do not take into account the cost of materials.

The costs of power electricity for development are calculated using the formula:

$$B_e = W_{yi} \cdot t_i \cdot P_e \cdot K_v/\eta_i \text{ [CU]}, \qquad (5.7)$$

where: P – cost of 1 kWh of electricity. As of May 2025, for industry (2nd category of consumers), the price of electricity is Pw = 0.210 CU/kW according to the market operator's tariffs, Pd = 0.053 CU/kW for the distribution of electricity according to the tariffs of Enera Vinnytsia LLC (as an example) and Ps = 0.01 CU/kW for the supply of electricity to a specific user according to the tariffs of Enera Vinnytsia LLC (as an example).

W – installed capacity of the equipment;

t – the actual number of hours of equipment operation during technological operations, resulting in the production of one product;

K is the capacity utilization factor.

Pe = (0.21+0.053+0.01)(1+20%/100%)= 0.328 (CU).

Table 5.6– Results of electricity cost calculations

Equipment name	Working hours, hours	Power, kW.	Utilization rate
Computer equipment	150	0.5	1
Room (lighting)	140	0.9	1
Industrial robot	110	6	1
Auxiliary equipment	120	6	0.8

$$Pe1 = 0.328 \cdot 0.5 \cdot 150 \cdot 1 = 24.6 \text{ (CU)},$$

$$Pe2 = 0.328 \cdot 0.9 \cdot 140 \cdot 1 = 41.34 \text{ (CU)},$$

$$Pe3 = 0.328 \cdot 6 \cdot 110 \cdot 1.0 = 216.5 \text{ (CU)},$$

$$Pe4 = 0.328 \cdot 6 \cdot 120 \cdot 0.8 = 189 \text{ (CU)},$$

$$Pe = 24.6 + 41.34 + 216.5 + 189 = 471.4 \text{ (CU)}.$$

Other costs can be taken as (100…300)% of the basic salary of the workers who performed this work:

$$I_{в}=(1\ldots3)\ (S_m+S_{add})\ , \tag{5.8}$$

$$Iv = 3 \cdot (8863+990) = 29559 \text{ (CU)}$$

All costs are:

$$B = 8863+990+ 1182 + 2428+ +1320 +$$
$$+ 471.4 + 29559 = 44813 \text{ (CU)}$$

Calculation of the total costs of performing this work by all performers.

The total cost of this work is determined by the B_{total} formula:

$$B_{\text{total}} = \frac{B}{\alpha}, \tag{5.9}$$

where α– the share of costs directly incurred by the performer of this stage of work, in relative units. For our caseα= 0.95.

Then

$$B_{\text{total}} = 44813 / 0.95 = 47171 \text{ (CU)};$$

Forecasting of total costs is carried out using the formula:

$$ZV = B_{total} / \beta, \qquad (5.10)$$

where is the coefficient that characterizes the stage (stage) of the performance of this work. Thus, if the development is: at the stage of scientific and research work, then $\beta \approx 0.1$; at the stage of technical design, then $\beta \approx 0.2$; at the stage of development of design documentation, then $\beta \approx 0.3$; at the stage of technology development, then ≈ 0.4; at the stage of development of a prototype, then $\beta \approx 0.5$; at the stage of development of an industrial prototype, $\beta \approx 0.7$; at the stage of implementation, then $\beta \approx$ 0.8-0.9.

For our case $\beta \approx 0.4$.

Then:

$$ZV = 47171 / 0.4 = 117928 \text{ (CU)}$$

That is, the projected costs for developing a combined processing method and implementing the results of this work are approximately 117928 CU.

5.3 Assessment of the importance and scientific significance of scientific research work of a fundamental or exploratory nature

To substantiate the feasibility of carrying out scientific research work, a special complex indicator is used, which takes into account the importance, effectiveness of the work, the possibility of implementing its results in production, the amount of work costs

The complex indicator KP of the level of scientific research work can be calculated by the formula:

$$K_P = \frac{I^n \cdot T_C \cdot R}{B \cdot t} \quad (5.11)$$

Where

I is the coefficient of importance of the work, I = 2...5;

n is the coefficient of use of the results of the work; n = 0, when the results of the work will not be used; n =1, when the results of the work will be used partially; n = 2, when the results of the work will be used in research and development; n = 3, when the results can be used even without conducting research and development;

T_C is the coefficient of complexity of the work, 1...3 T_C =1..3 ;

R – efficiency coefficient; if the results of the work are planned above the known ones, then R = 4; if the results of the work correspond to the known level, then R = 3; if below the known results, then R =1;

B – cost of research work, thousand CU;

t – research time, years.

$$K_P = \frac{4^3 \cdot 3 \cdot 4}{117{,}9 \cdot 4} = 1{,}63$$

K_P=1.63 > 1, then research work can be considered effective with high scientific, technical and economic levels.

5.4 Conclusions to the section

When assessing the economic efficiency of scientific research, the commercial potential of the research was determined and an estimate of capital costs for the modernization of the machining area was calculated, as well as the economic efficiency of the innovative solution was assessed.

The commercial potential of the study, according to the results of a survey of experts, was determined as above average.

Research work can be considered effective with high scientific, technical and economic levels.

CONCLUSIONS

1. Based on the review of typical automation tools, the main methodologies and means for production automation can be identified, namely the use of robotic equipment and auxiliary devices in combination with CNC machine tools.
2. Automated or robotic elements usually perform auxiliary functions.
3. Robots with 4 to 6 degrees of freedom are typically used for servicing the machine tool.
4. At the workstation, industrial robots perform primary automation tasks, including automated loading and unloading operations.
5. A technological process for the mechanical machining of the "Support" part blank has been developed.
6. A dimensional analysis of the technological process was conducted, and machining allowances for the hole and cutting modes were calculated.
7. Performing dimensional analysis made it possible to determine the technological dimensions and the workpiece dimensions.
8. A machining program for a CNC machine was created using the SolidCAM system.
9. Based on the analysis of the feasibility of automation, operation 015 was selected, as automation in this case can reduce auxiliary time losses.
10. A list of actions and the equipment required to perform them in an automated workstation was determined.
11. A general algorithm for the operation of the automated workstation for machining the “Support" part has been developed.
12. The "Universal" industrial robot model was selected for use in the automated workstation.
13. A gripper device scheme was selected for handling the "Support" part.
14. Time expenditures were calculated, and dependencies of the robot’s speed and time characteristics on the manipulator's features and the mass of the handled load were studied.

15. The parameters of the workstation’s operation were defined. The total cycle time is 81 seconds.
16. In assessing the economic efficiency of the research, the commercial potential of the study, according to the results of a survey of experts, was determined as above average.
17. Research work can be considered effective with high scientific, technical and economic levels

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APPENDICES

APPENDIX A

(required)

ILLUSTRATIVE PART

DESIGN OF AN AUTOMATED WORKPLACE FOR THE TECHNOLOGICAL PROCESS OF MACHINING OF THE PART "SUPPORT"

Purpose and objectives of the work

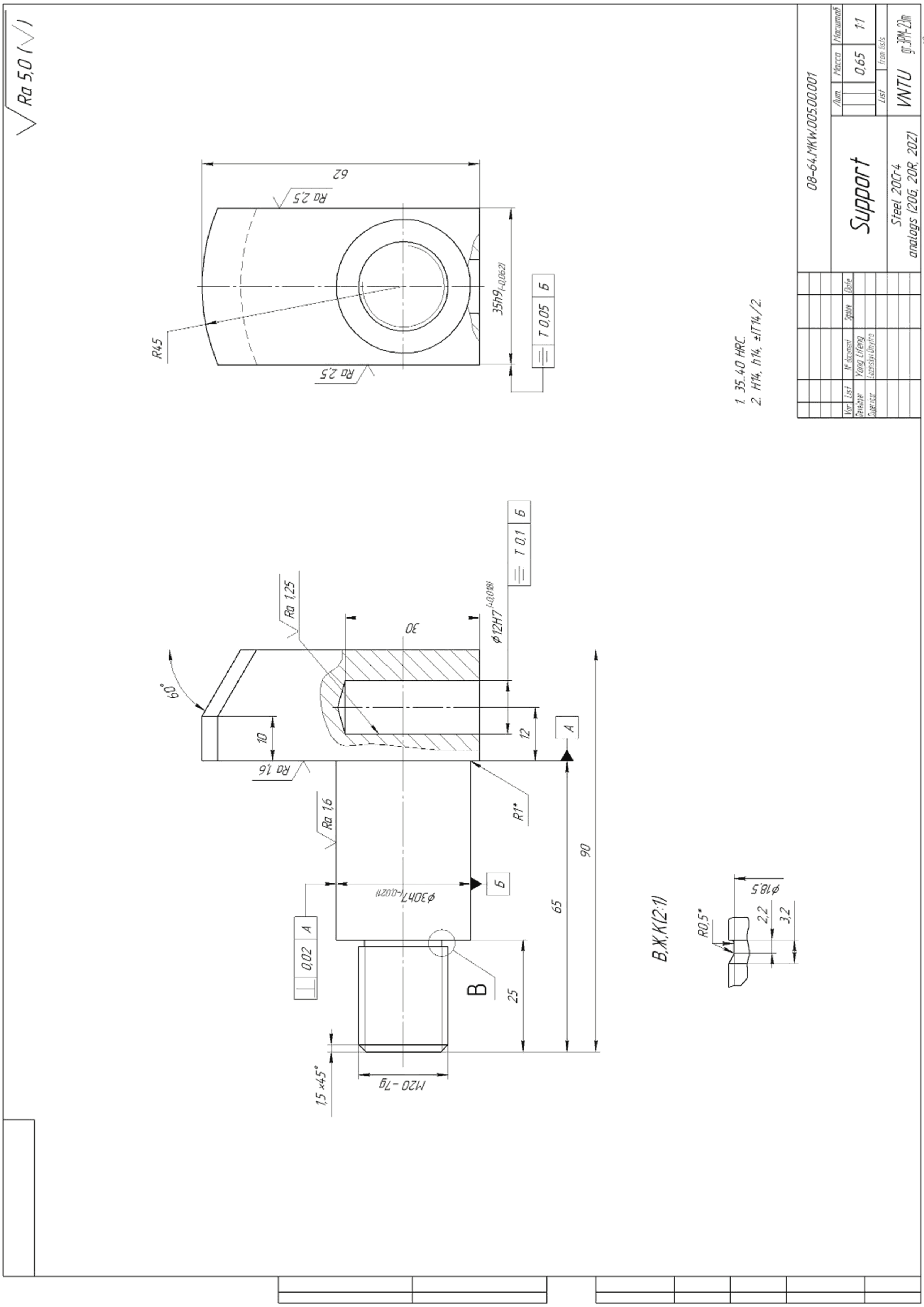
The purpose of the work is to automate the workplace of the technological process of machining the workpiece “Support”.

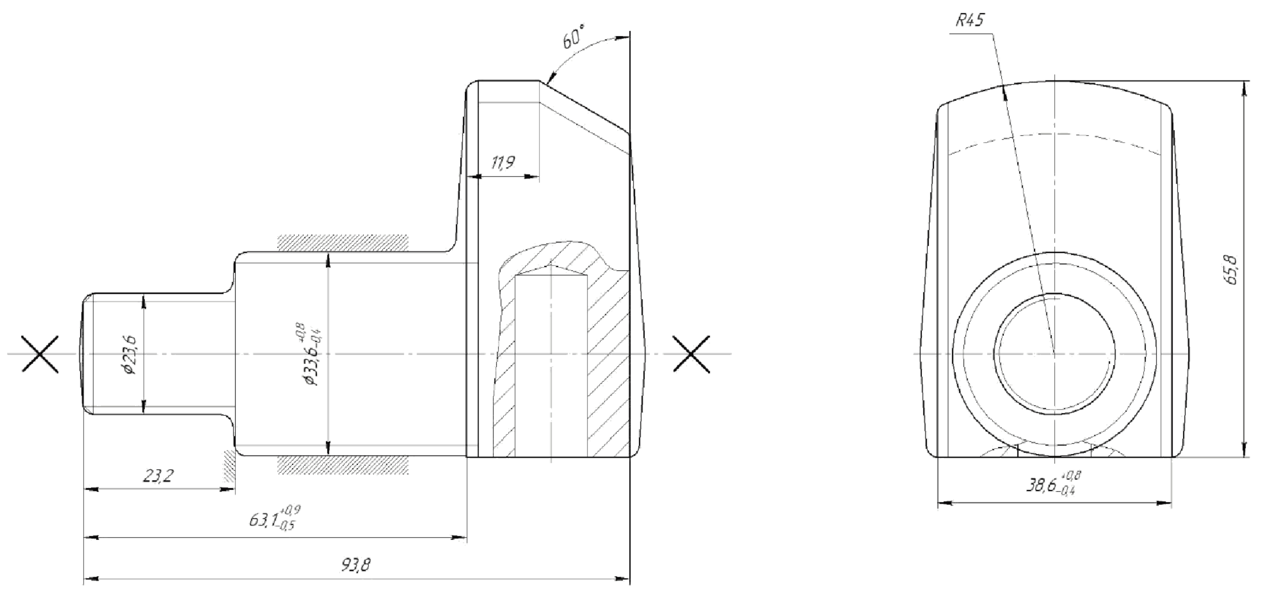
To achieve the set goal, the following tasks must be performed:

- to review known methods and automation tools used in technological production;
- to analyze the machining route and determine operations that can be automated;
- to develop a general scheme of the automated workplace and the algorithm of the automated workplace;
- to select technological equipment and design automated equipment for it;
- to calculate the main parameters of the automated workplace;
- to develop the layout of the automated workplace;
- to calculate and analyze the economic feasibility of manufacturing the part;
- to analyze working conditions and safety in emergency situations.

The object of the study is the automated workplace of the technological process of machining the workpiece " Support ".

The subject of the study is the technological process of machining the part “Support".

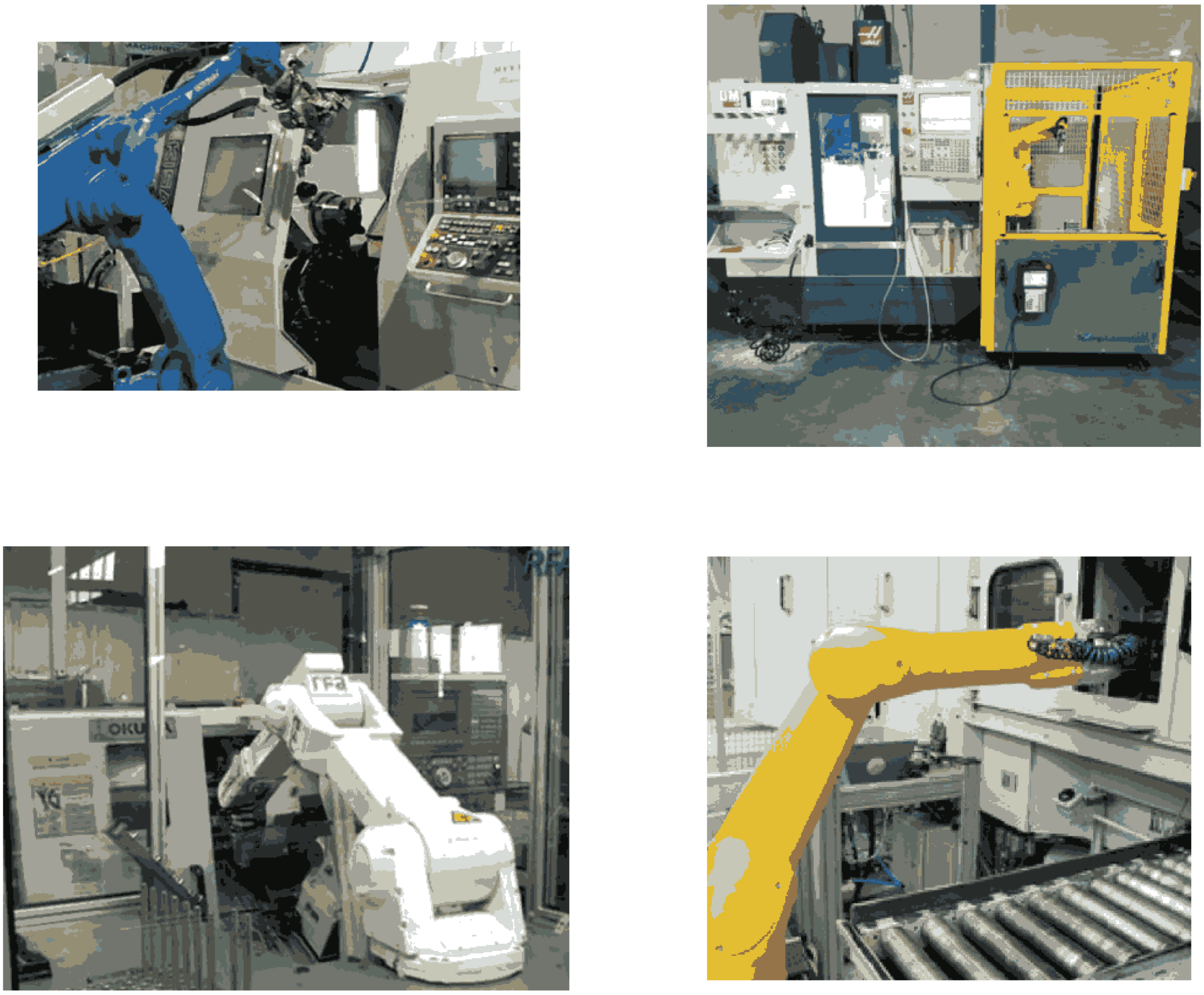

Ra 5,0
62
Ra 2,5
R45
35h9(-0,062)
T 0,05 Б
Ra 1,25
30
ϕ12H7(+0,018)
T 0,1 Б
60°
10
12
A
Ra 1,6
R1*
ϕ30h7(-0,021)
Б
0,02 A
65
90
25
B
1,5×45°
M20-7g
B,Ж,К(2:1)
R0,5*
ϕ18,5
2,2
3,2
1. 35...40 HRC.
2. H14, h14, ±IT14/2.
08-64.MKW.005.00.001
Support
Steel 20Cr4
analogs (20G, 20R, 20Z)
0,65
1:1
VNTU



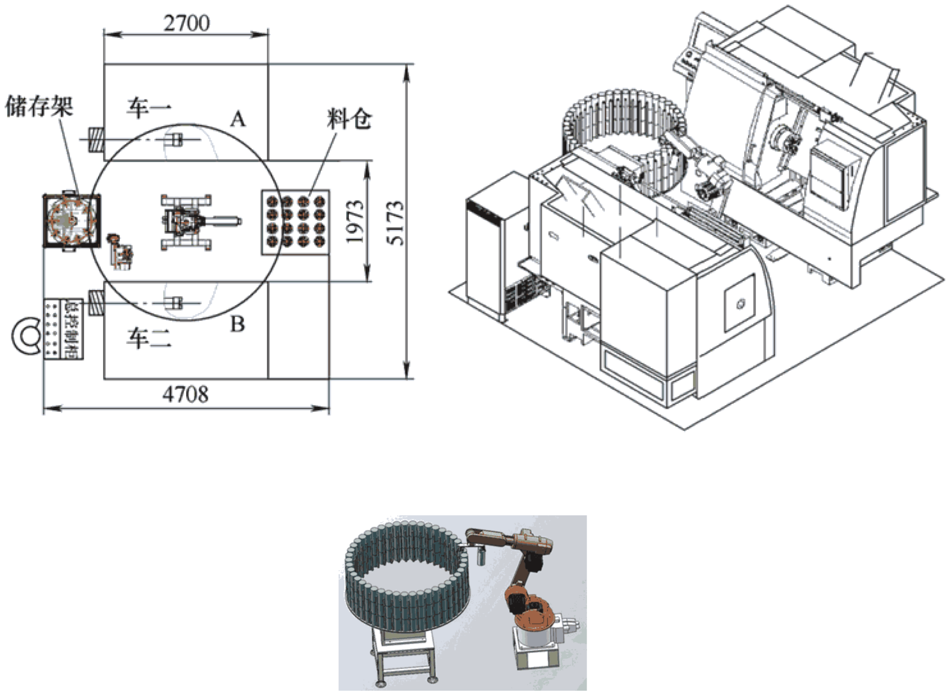
1.T4-M1-S2 GOST 7505-74.
2.Unspecified stamping slopes 4, radii 2 mm.
3.Permissible burr 3 mm.
4.Permissible displacements along the plane of the connector 0.6 mm.
5.Unspecified tolerances of rounding radii 0.4 mm.

					08-64.MKW.005.00.002			
Var.	List	№ document	Signature	Date	Support (workpiece)	Лит.	Масса	Масштаб
Developer		Yang Lifeng					0,8	1:1
Supervisor		Lozinskyi Dmytro				List	from lists	
					Steel 20Cr4 analogs (20G, 20R, 20Z)	VNTU	gr.3PM-23m	

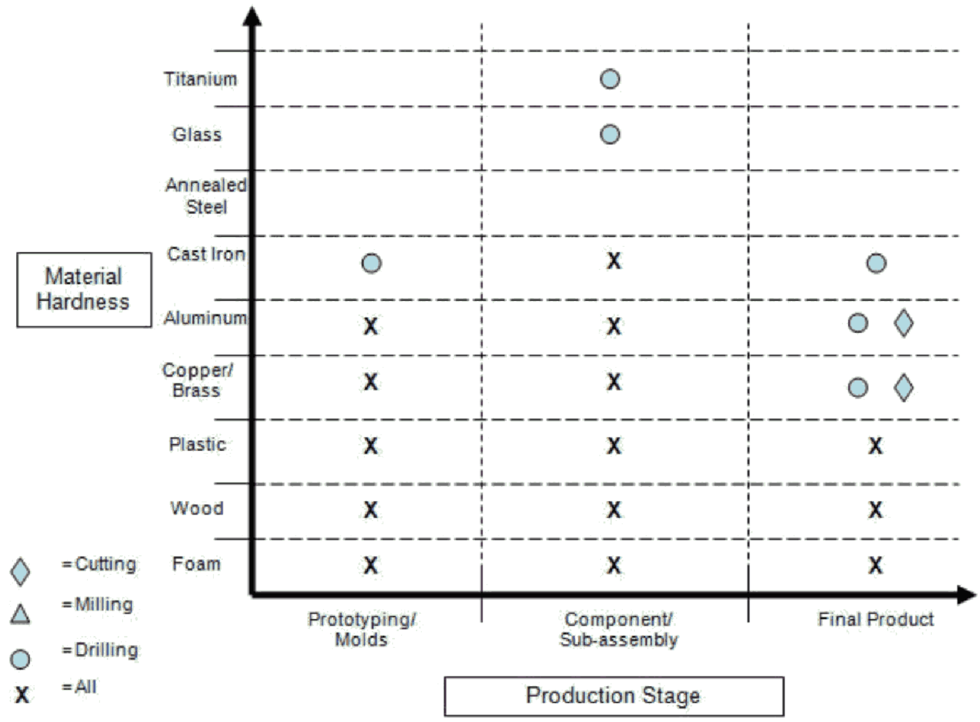
A2



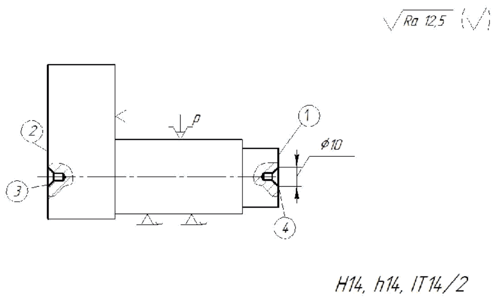
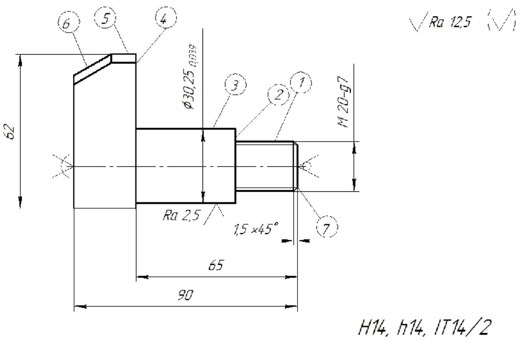
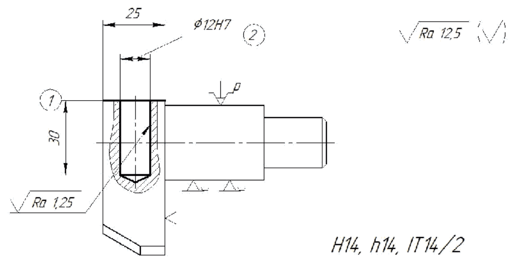
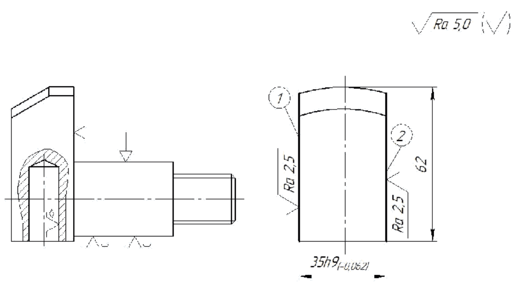
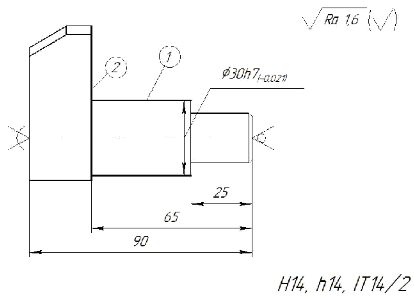
Application of robots in machining



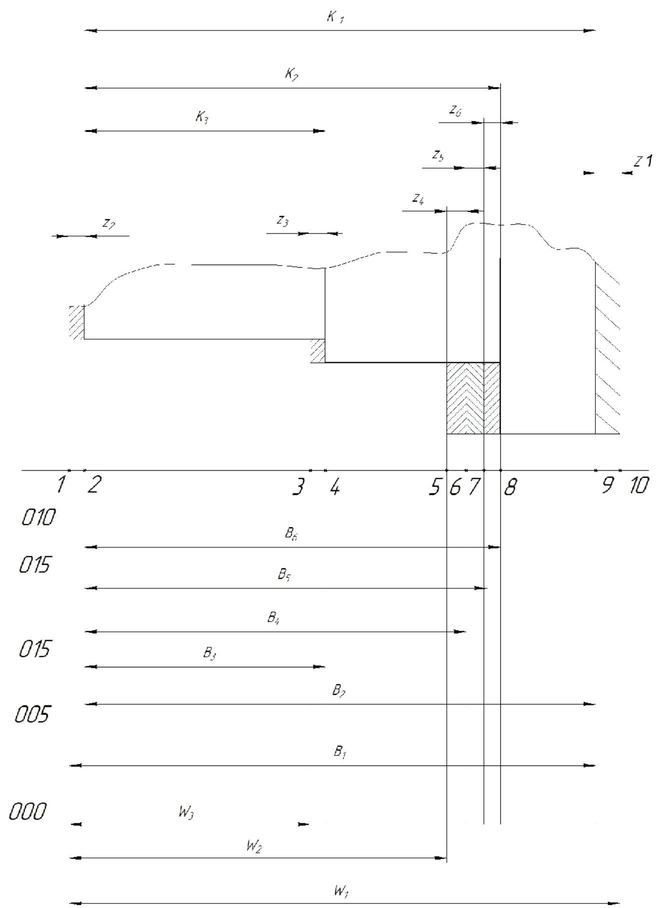
Application of robots in machining



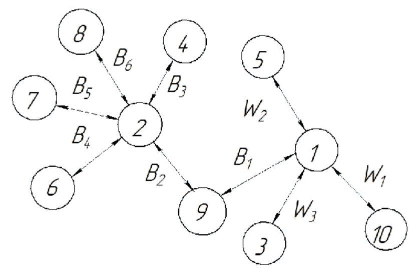
Materials and operation which can be machined

№ operation	Operation name with number of transitions	Installation diagram	Equipment type and model
005	Milling and centering 1. Install and secure the part. 2. Mill ends 1 and 2 once. 3. Center holes 3 and 4 once. 4. Remove the part.		Milling and centering machine MR-71M
010	CNC lathe 1. Install and secure the part. 2. Grind surface 1, end 2 once, surface 3 preliminary and surface 3 final. 3. Grind end 4 preliminary. 4. Grind end 4 final. 5. Grind surfaces 5 and 6 once. 6. Grind chamfer 7 once. 7. Cut a thread on surface 1. 8. Remove the part.		CNC lathe 16K20F3
015	Vertical drilling with CNC 1. Install and secure the part. 2. Mill surface 1 once. 3. Center hole 2. 4. Drill hole 2 once. 5. Pre-drill hole 2. 6. Final drill hole 2. 7. Remove the part.		Vertical drilling with CNC 2R135F3
020	Vertical milling with CNC 1. Install and secure the part. 2. Mill surfaces 1 and 2 preliminarily. 3. Mill surfaces 1 and 2 finally. 4. Remove the part.		Vertical milling with CNC GF2171MF3
025	Heat treatment		
030	End-cylindrical grinding 1. Install and secure the part. 2. Grind surface 1 and end 2. 3. Remove the part.		End-round-grinding 3T160

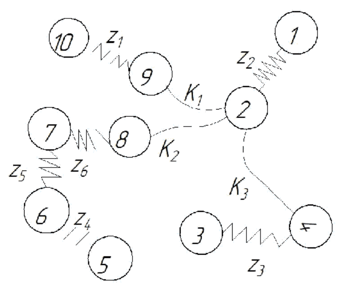
Dimensional analysis



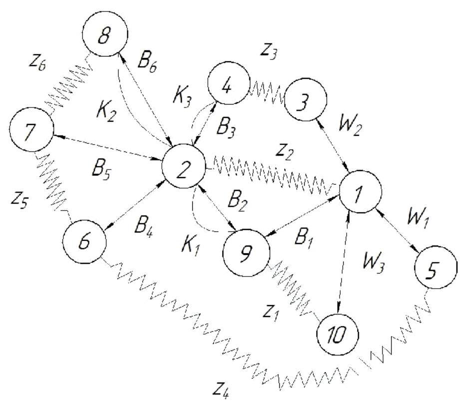
Derivative graph



Output graph



Adjacent graph



$K_1 = 90 \pm 0.435$

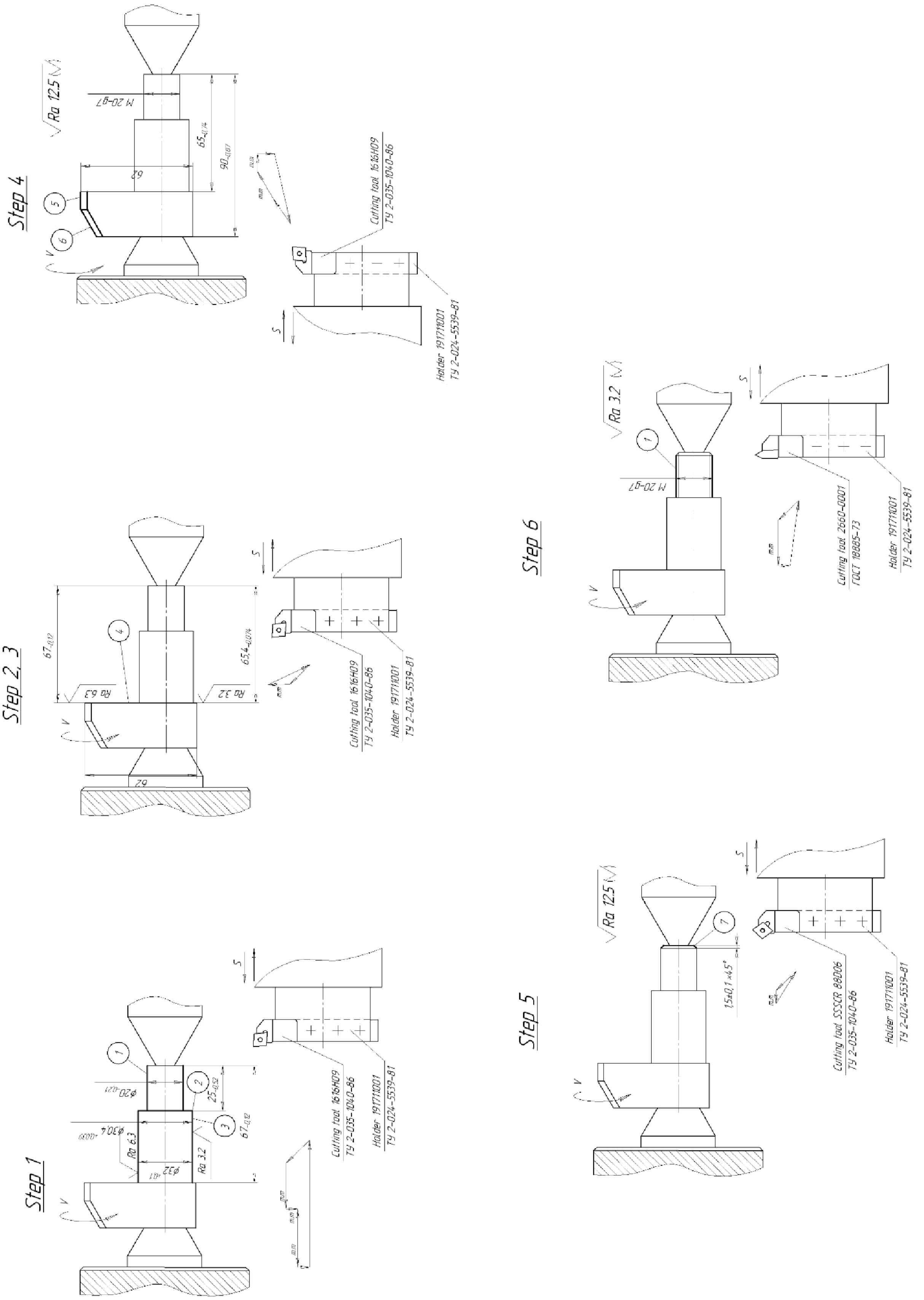
$K_2 = 65 \pm 0.37$

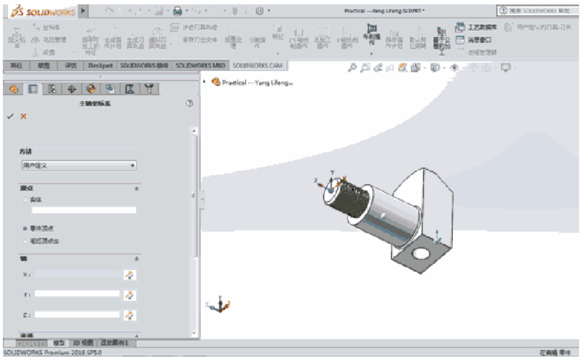
$K_3 = 25 \pm 0.26$

Allowances	Z1 min	Z2 min	Z3 min	Z4 min	Z5 min	Z6 min
Z3 min	2	2,1	2	2	1,2	0,8

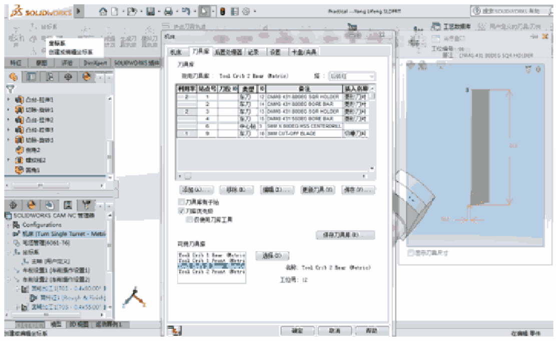
Size	B1	B2	B3	B4	B5	B6	W1	W2	W3
Admission, мм	0,87	0,87	0,62	0,3	0,074	0,03	1,4	1,2	1

Equation	Equation	Size
– K3+B3=0	K3 =B3	B3
– K2+ B6 =0	K2 = B6	B6
–K1 +B2 =0	K1= B2	B2
Z2+B2–B1=0	B1= Z2+ B2	B1
Z1+B1– W1=0	W1= B1+ Z1	W1
B5+ Z6 – B6=0	B5=B6– Z6	B5
B4+ Z5– B5 =0	B4= B5– Z5	B4
Z4– B4+ Z2+W2=0	Z4= B4– Z2– W2	W2
Z3–B3 +W3+Z2=0	Z3= B3 –W3– Z2	W3

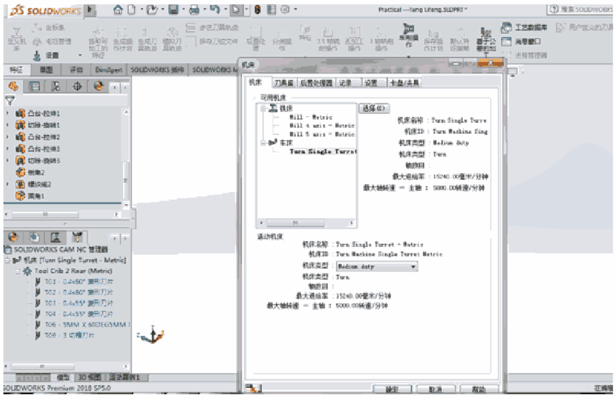

Step 4
Ra 12.5
M 20-g7
Cutting tool 1616H09
ТУ 2-035-1040-86
Holder 191711001
ТУ 2-024-5539-81
Step 2, 3
Ra 6.3
Ra 3.2
Cutting tool 1616H09
ТУ 2-035-1040-86
Holder 191711001
ТУ 2-024-5539-81
Step 1
Ra 6.3
Ra 3.2
Cutting tool 1616H09
ТУ 2-035-1040-86
Holder 191711001
ТУ 2-024-5539-81
Step 6
Ra 3.2
M 20-g7
Cutting tool 2660-0001
ГОСТ 18885-73
Holder 191711001
ТУ 2-024-5539-81
Step 5
Ra 12.5
Cutting tool SSSCR 88006
ТУ 2-035-1040-86
Holder 191711001
ТУ 2-024-5539-81



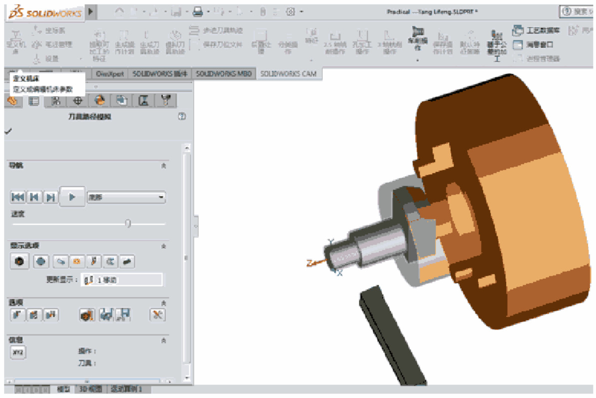
Open the part to be processed



Tool selection and settings



enter the machine tool settings

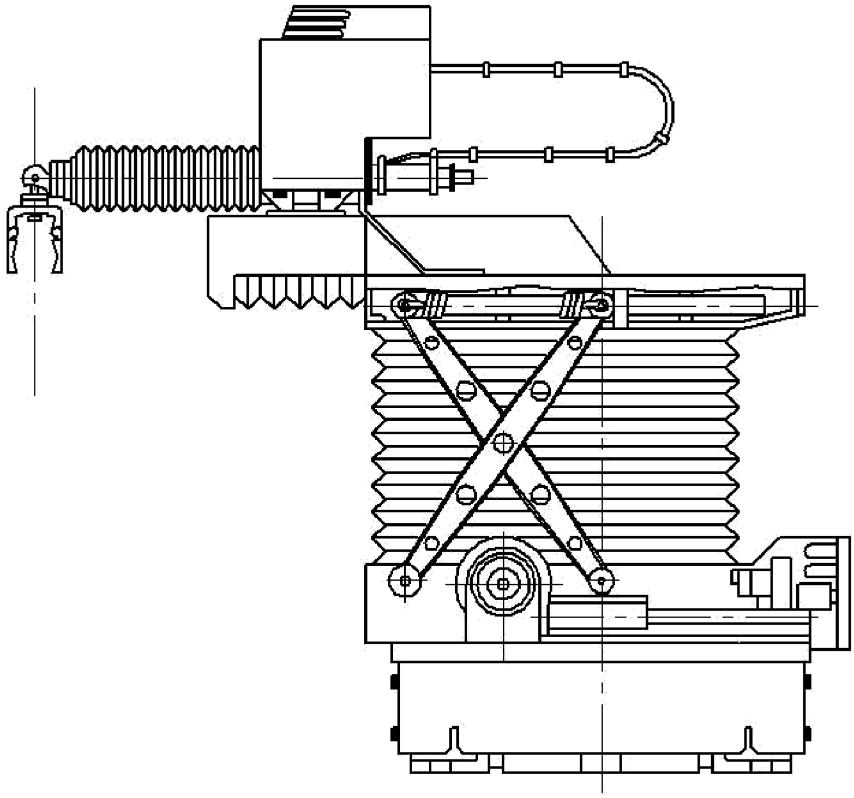


trajectory to run

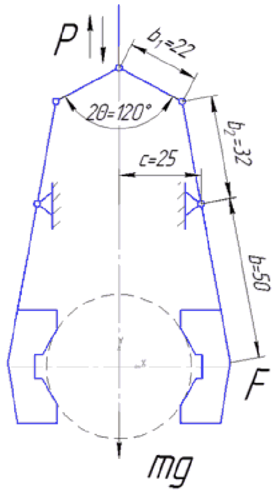
Using SolidWorks CAM for programming CNC machine-tools

Type of Work	**Technological Element**
Preparation of the workpiece for feeding, installation in auxiliary equipment	Fixtures for preliminary orientation of workpieces; the installation can also be performed by a worker for one or more shifts.
Picking up the workpiece with a manipulator	Industrial robot
Placing the workpiece on the machine	Industrial robot, developed machine tooling
Machining the workpiece on the machine	Machine, developed machine tooling
Removing the workpiece from the machine	Industrial robot, machine tooling
Transferring the workpiece to the assembly area for finished parts	Industrial robot
Changing elements of the automated station to prepare for the next workpiece	Indexing table

General algorithm of operation of the automated workstation



Industrial robot Universal



$$F = K_1 K_2 K_3 mg$$

where m is the mass of the manipulated object (mass of the workpiece);

g – acceleration of free fall;

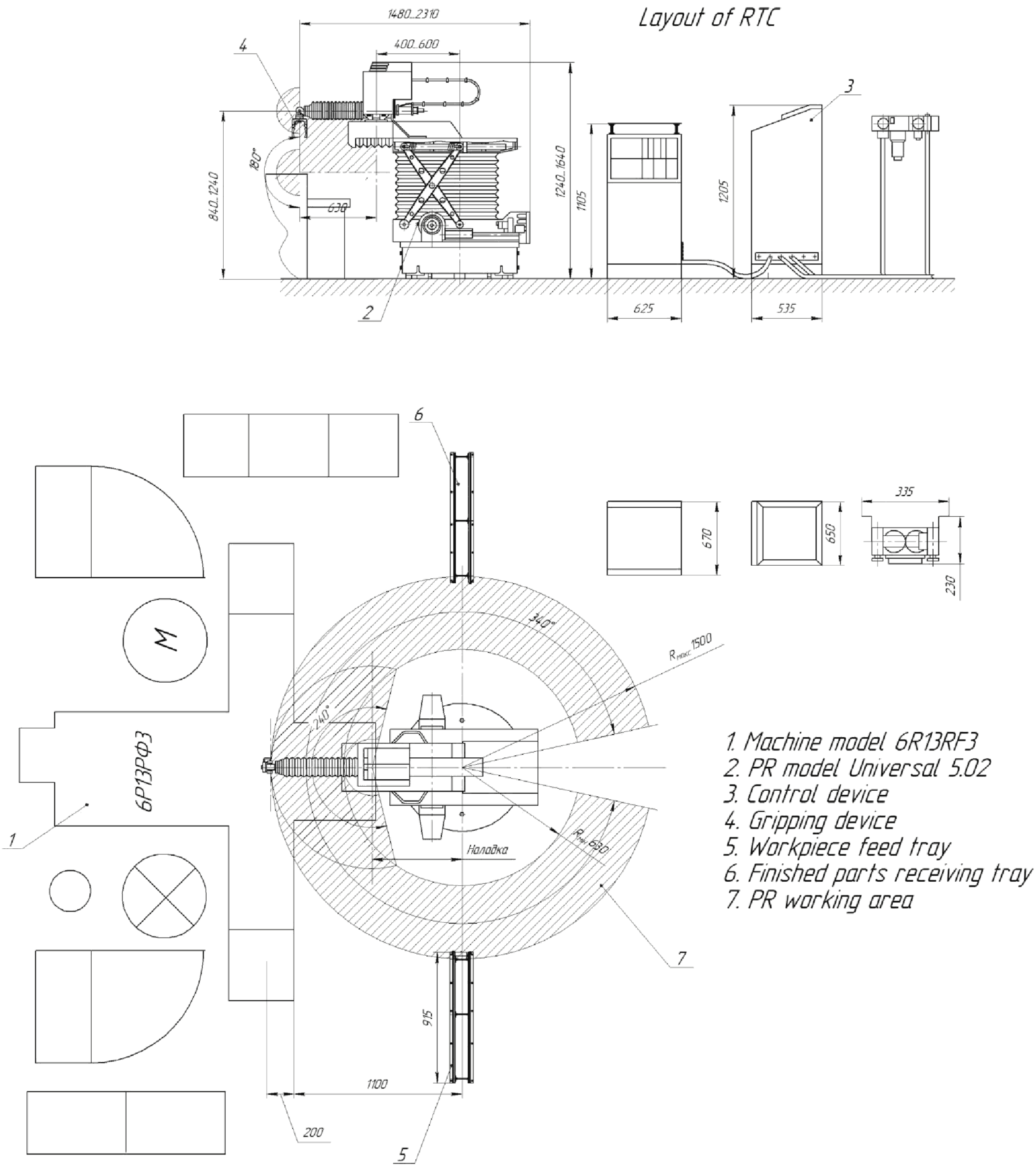
K1 – safety factor, K1=1.2 – 2.0. We assume K1=1.2;

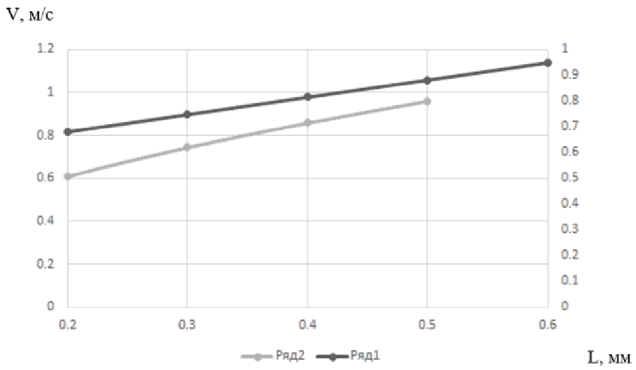
K2 is a coefficient depending on the maximum acceleration A with which the robot moves an object fixed in the gripping device. For pneumatic robots A g. K2=1+A/g=1.8;

K3 – transmission coefficient, depending on the design of the grip and the location of the manipulated object in it

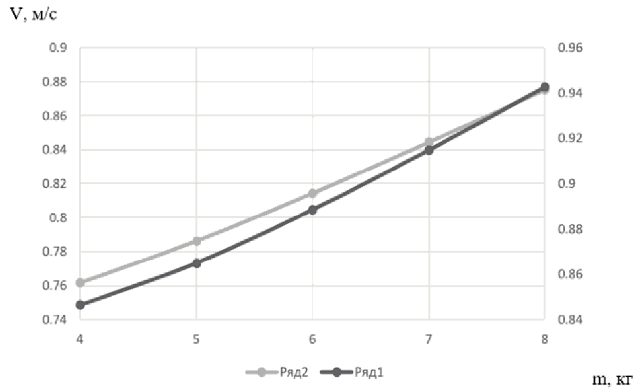
$$P = \frac{2 \cdot b \cdot F}{\left[tg\Theta \sqrt{1 - \left(\frac{b_1 \sin\Theta - c}{b} \right)^2} - \frac{b_1 \sin\Theta - c}{b} \right] \cdot b_2}$$

Gripper Device Diagram

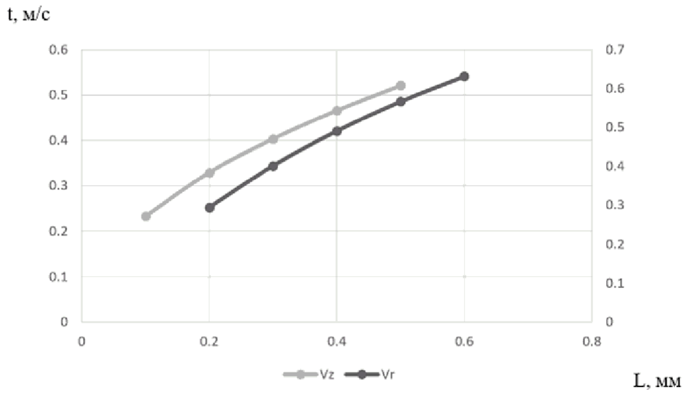

Layout of RTC
1480...2310
400...600
4
3
180°
840...1240
630
1240...1640
1105
1205
2
625
535
6
335
670
650
230
340°
R макс 1500
240°
6Р13РФ3
1
Наладка
R мин 690
7
915
1100
200
5
1. Machine model 6R13RF3
2. PR model Universal 5.02
3. Control device
4. Gripping device
5. Workpiece feed tray
6. Finished parts receiving tray
7. PR working area



Dependence of movement speed along the X and Z axes on the maximum reach



Dependence of movement speed along the X and Z axes on the mass

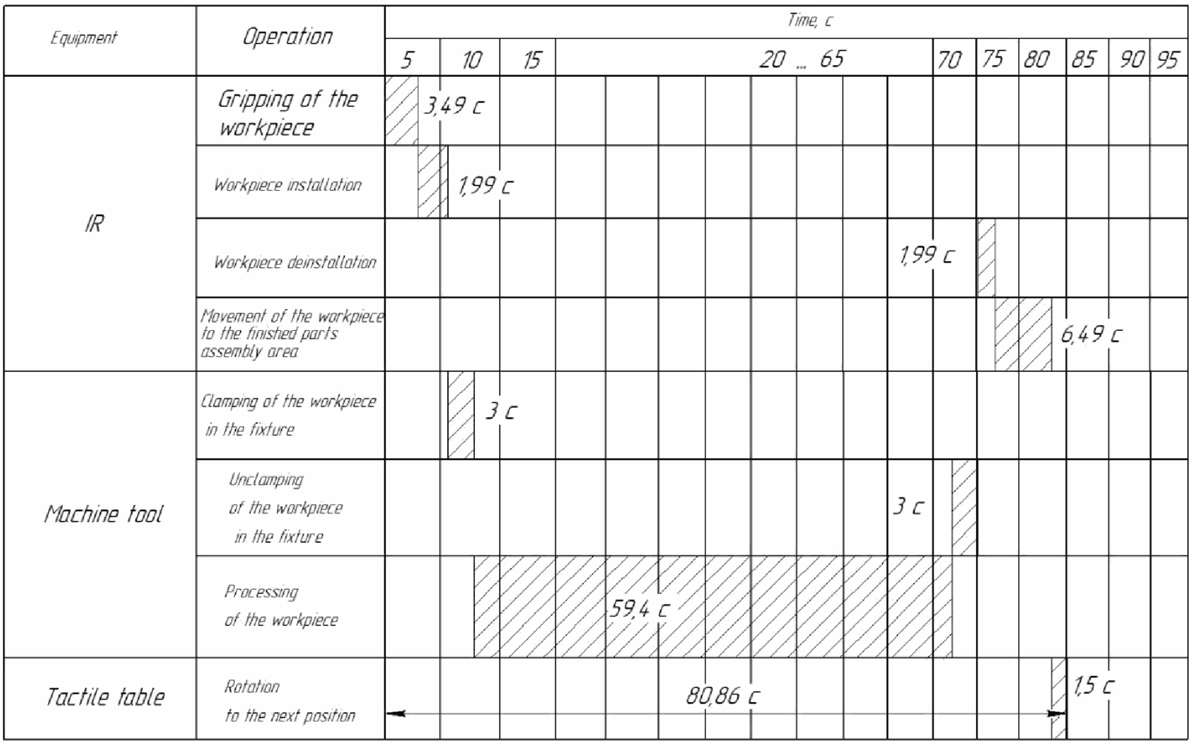


Dependence of movement time along the X and Z axes on the maximum reach

Cycle diagram of operation and algorithm of the RTC

Trajectory element	Comment	Displacement, mm(degrees)
r0 1	Moving the right hand forward	500
	Workpiece clamp	–
z1 2	Moving the right hand up	200
r2 3	Moving the left hand back	500
fi 3 4	Turn the left hand clockwise	90°
r4 5	Moving the right hand forward	500
z5 6	Moving the left hand down	200
	Blanking of the workpiece	–
r6 7	Moving the left hand back	500
	Hands up PR	–
r7 8	Moving the right hand forward	500
	Workpiece clamp	–
z8 9	Moving the right hand up	200
r910	Moving the left hand back	500
fi 1011	Turn the left hand clockwise	90°
r1112	Moving the right hand forward	500
z1213	Moving the left hand down	200
	Blanking of the workpiece	–
r1314	Moving the left hand back	500
fi 1415	Hand rotation against the left hand counterclockwise	180°

Algorithm of the RTC



Cycle diagram of operations

APPENDIX B

(required)

Part processing program on a CNC machine tool

```
O0001
N1 (CNMG 431 80DEG SQR HOLDER)
N2 T0101
N3 B90.
N4 G00 G96 S548 M03

N5 ( —f2 )
N6 G54 G00 Z3.354 M08
N7 X100.707
N8 G01 X94. Z0 F.409
N9 Z-90.4
N10 X94.707 Z-90.754
N11 G00 X100.707
N12 Z.354
N13 X89.074
N14 G01 X88.367 Z0
N15 Z-63.5
N16 X89.2
N17 G03 X93. Z-65.4 R1.9
N18 G01 Z-75.4
N19 G03 X92.972 Z-75.632 R1.9
N20 G01 X89.345 Z-90.4
N21 X89.961 Z-90.794
N22 G00 X95.961
N23 Z.354
N24 X83.442
N25 G01 X82.734 Z0
N26 Z-63.5
N27 X88.367
N28 X89.074 Z-63.146
N29 G00 X95.074
N30 Z.354
N31 X77.809
N32 G01 X77.102 Z0
N33 Z-63.5
N34 X82.734
N35 X83.442 Z-63.146
N36 G00 X89.442
N37 Z.354
N38 X72.176
N39 G01 X71.469 Z0
N40 Z-63.5
N41 X77.102
N42 X77.809 Z-63.146
N43 G00 X83.809
N44 Z.354
N45 X66.543
N46 G01 X65.836 Z0
N47 Z-63.5
N48 X71.469
N49 X72.176 Z-63.146
N50 G00 X78.176
```

```
N51 Z.354
N52 X60.91
N53 G01 X60.203 Z0
N54 Z-63.5
N55 X65.836
N56 X66.543 Z-63.146
N57 G00 X72.543
N58 Z.354
N59 X55.278
N60 G01 X54.571 Z0
N61 Z-63.5
N62 X60.203
N63 X60.91 Z-63.146
N64 G00 X66.91
N65 Z.354
N66 X49.645
N67 G01 X48.938 Z0
N68 Z-63.5
N69 X54.571
N70 X55.278 Z-63.146
N71 G00 X61.278
N72 Z.354
N73 X44.012
N74 G01 X43.305 Z0
N75 Z-63.5
N76 X48.938
N77 X49.645 Z-63.146
N78 G00 X55.645
N79 Z.354
N80 X38.379
N81 G01 X37.672 Z0
N82 Z-63.5
N83 X43.305
N84 X44.012 Z-63.146
N85 G00 X50.012
N86 Z.354
N87 X32.747
N88 G01 X32.04 Z0
N89 Z-24.137
N90 G03 X33. Z-25.4 R1.9
N91 G01 Z-63.5
N92 X37.672
N93 X38.379 Z-63.146
N94 G00 X44.379
N95 Z.354
N96 X27.114
N97 G01 X26.407 Z0
N98 Z-23.5
N99 X29.2
N100 G03 X32.04 Z-24.137 R1.9
N101 G01 X33.038 Z-24.167
N102 X33.938
```

```
N103 G00 X39.038
N104 Z.5
N105 X23.514
N106 G01 X20.774
N107 Z0
N108 X21.887 Z-.556
N109 G03 X23. Z-1.9 R1.9
N110 G01 Z-23.5
N111 X26.407
N112 G00 X30.207 Z-23.165
N113 Z.666
N114 X17.614
N115 G01 Z.166
N116 X20.473 Z-1.264
N117 G03 X21. Z-1.9 R.9
N118 G01 Z-24.5
N119 X29.2
N120 G03 X31. Z-25.4 R.9
N121 G01 Z-64.4
N122 G02 X31.2 Z-64.5 R.1
N123 G01 X89.2
N124 G03 X91. Z-65.4 R.9
N125 G01 Z-75.4
N126 G03 X90.987 Z-75.51 R.9
N127 G01 X87.318 Z-90.449
N128 X87.934 Z-90.843
N129 G00 X105.2
N130 X508. Z127. M09
N131 M01

N132 (DNMG 431 80DEG SQR HOLDER)
N133 T0303
N134 B90.
N135 G00 G96 S548 M03

N136 ( sf2 )
N137 G54 G00 Z3.383 M08
N138 X22.766
N139 G01 X16.766 Z.383 F.409
N140 Z-.117
N141 X19.766 Z-1.617
N142 G03 X20. Z-1.9 R.4
N143 G01 Z-25.
N144 X29.2
N145 G03 X30. Z-25.4 R.4
N146 G01 Z-64.4
N147 G02 X31.2 Z-65. R.6
N148 G01 X89.2
N149 G03 X90. Z-65.4 R.4
N150 G01 Z-75.4
N151 G03 X89.925 Z-75.569 R.4
N152 G01 X75.936 Z-90.569
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N153 X76.278 Z-91.039
N154 G00 X96.
N155 X508. Z127. M09
N156 M01

N157 (3MM CUT-OFF BLADE)
N158 T0909
N159 B90.
N160 G00 G97 S1384 M04

N161 (
-2 )
N162 G54 G00 Z-90. M08
N163 X88.011
N164 G01 Z-93. F.091
N165 X70.011
N166 G00 X76.011
N167 G01 X64.011
N168 G00 X70.011
N169 G01 X58.011
N170 G00 X64.011
N171 G01 X52.011
N172 G00 X58.011
N173 G01 X46.011
N174 G00 X52.011
N175 G01 X40.011
N176 G00 X46.011
N177 G01 X34.011
N178 G00 X40.011
N179 G01 X28.011
N180 G00 X34.011
N181 G01 X22.011
N182 G00 X28.011
N183 G01 X16.011
N184 G00 X22.011
N185 G01 X10.011
N186 G00 X16.011
N187 G01 X4.011
N188 G00 X10.011
N189 G01 X-.4
N190 G00 X84.679
N191 X508. Z127. M09
N192 M30
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APPENDIX C

PROTOCOL OF VERIFICATION OF QUALIFICATION WORK

Title of work: Design of an automated workplace for the technological process of machining of the part "Support"

Type of work: master's qualification thesis
(bachelor's thesis / master's thesis)

Subdivision department of TAME, FMET, group 3PM-23m
(department, faculty, study group)

The similarity coefficient of text borrowings identified in the work by StrikePlagiarism system 2.94 %

Conclusion on the verification of qualification work (check as appropriate)

- [x] Borrowings found in the work are legal and do not contain signs of plagiarism, fabrication, or falsification. The work is accepted for defense.

- [ ] The work does not reveal any signs of plagiarism, fabrication, or falsification, but the excessive number of textual borrowings and/or the presence of typical calculations do not allow for a decision on the originality and independence of its execution. The work should be sent for revision.

- [ ] The work contains signs of plagiarism and/or text manipulation as attempts to conceal plagiarism, fabrication, or falsification, which is contrary to the requirements of the law and the norms of academic integrity. The work will not be accepted for defense.

Expert Commission:

Leonid KOZLOV, Head of the Department of TAME
(name, surname, position) (signature)

Olha SERDIUK, Guarantor of the OPP
(name, surname, position) (signature)

Person responsible for verification (signature) Olha SERDIUK
(first name, last name)

I have been informed of the conclusion of the expert commission.

Supervisor (signature) Dmytro LOZINSKIY
(name, surname, position)

Student Lifeng YANG. (signature) Lifeng YANG
(name, surname)