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For the degree of

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topic: Development of body structure 732141.147 production technology and the study of thin-walled components of machine parts machining

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ABSTRACT

The qualifying paper topic: “Development of body structure 732141.147 production technology and the study of thin-walled components of machine parts machining.”

In the qualifying paper the dynamics of the cylindrical part with thin-walled ribbed elements turning is studied. The system of differential equations describing the oscillations of the elements of the equivalent multimass system is derived. The solution of the system of differential equations is performed using application software that uses a subroutine of the Runge-Kutta numerical method with initial coordinates determined from equations. The solution is presented in the form of numerical data and graphs.

Based on the constructed graphs it is established that the deformations of the thin-walled ribbed element in time have a variable character with a sharp increase at the time of impact with the cutter. After the impact, the oscillations of such element are damped.

The results of experimental studies for determination of the roughness of thin-walled ribbed elements after turning in workpieces from steel 45 depending on changes in three main factors: cutter feed, depth of cut and thickness of thin-walled ribbed element are presented.

The technological process of the body structure 732141.147 manufacturing is improved. The workpiece is defined, locating schemes are developed, cutting tools, equipment, cutting conditions are selected and fixtures are designed.

CONTENTS

INTRODUCTION

Parts with thin-walled elements obtained by machining on modern machine tools are widely used in various industries. Vibrations occur when machining such parts. This degrades the roughness of the machined surfaces and leads to the decrease in dimensional accuracy. Achieving low surface roughness is very important for such parts.

The existence of vibrations during parts machining not only reduces the tool life, but also leads to increased wear of the machine tool spindle unit. Also, due to the elastic deformation of the part, the defined allowance is not completely cut, leading to deviations in the shape and location of the nominal profile.

To reduce the vibrations of thin-walled elements during machining include methods: the use of step-by-step machining with alternate removal of allowance on each side of the thin-walled part; making the last pass without setting the allowance; forecasting of machining conditions by the method of petal diagrams (stability diagrams); application of cutting tools with variable geometry; application of modulation for the main movement speed; increasing the rigidity of thin-walled elements of parts through the use of special technological environments, etc.

The peculiarity of the thin-walled elements turning is that in the process of cutting there are impact loads and deformations of the workpiece material. Therefore, the study of the dynamics of such process is the actual task.

Also actual task is improving of the technological process for the body structure 732141.147 manufacturing with defining of the workpiece, development of locating schemes, selection of cutting tools, equipment, cutting conditions and fixtures design.

1 ANALYTICAL PART

1.1. Analysis of the state of the issue

Parts with thin-walled elements obtained by machining on modern CNC machines are widely used in various industries. Examples of such parts are presented in the Fig. 1.1. Vibrations occur when machining such parts. This degrades the roughness of the machined surfaces and leads to the decrease in dimensional accuracy. Achieving low surface roughness is very important for such parts.

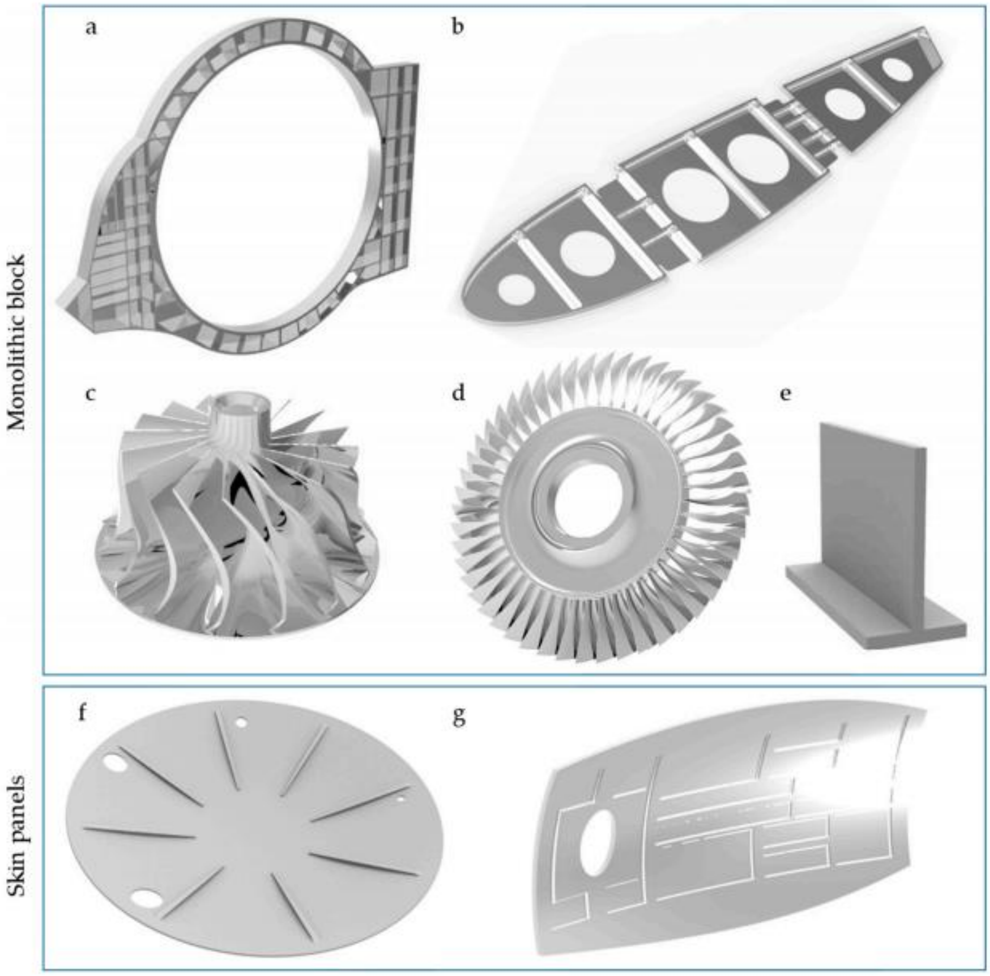


Figure 1.1 - Examples of parts with thin-walled elements [25]

The existence of vibrations during parts machining not only reduces the tool life, but also leads to increased wear of the machine tool spindle unit. Also, due to the elastic deformation of the part, the defined allowance is not completely cut, leading to the deviations in the shape and location of the nominal profile.

One of the effective technological methods for reducing of vibrations and improving dimensional accuracy during finish machining is the use of special technological environments that fill the space with thin-walled elements. Various materials of environments are used in this direction.

Modern ideas about the occurrence of vibrations during machining and methods of reducing their intensity are shown in the Fig. 1.2. based on the analysis of scientific works.

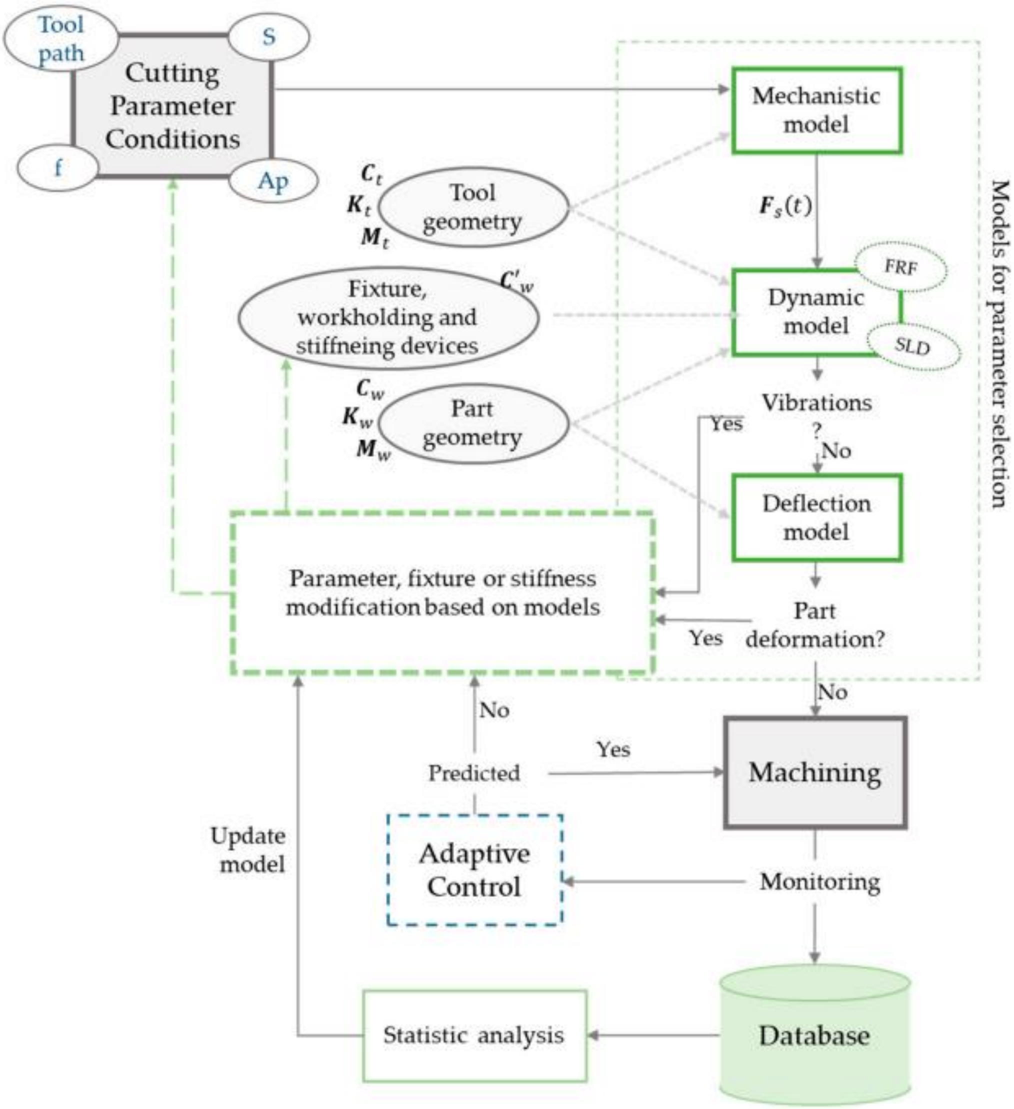


Figure 1.2 - Scheme of the process formation for machining of thin-walled elements of machine parts [25]

Such methods include: the use of step-by-step machining with alternate removal of allowance on each side of the thin-walled part; making the last pass without setting the allowance; forecasting of machining conditions by the method of petal diagrams (stability diagrams); application of cutting tools with variable geometry; application of modulation for the main movement speed; increasing the rigidity of thin-walled elements of parts through the use of special technological environments, etc.

The peculiarity of the thin-walled elements turning is that in the process of cutting there are impact loads and deformations of the workpiece material.

Experimental studies have shown that according to the oscillogram (Fig. 1.3) the zones of impact and forming interactions of the cutter and thin-walled elements of the workpiece are clearly distinguished.

t=1.0 mm; S=0.4 m/min; V=150 m/min; Pz=400 N

Figure 1.3 – The oscillogram of the thin-walled elements of the workpiece turning process [26]

In addition, the nature of the cutter deformation after removal of the load (at the end of cutting) indicates the significant scattering (dissipation) of mechanical energy and almost complete finishing of oscillating process in one period.

The general estimation of dynamic character of loading can be received on the basis of introduction of dynamism coefficient k_{∂}, as the relation of the deformation magnitude of the system at dynamic and static loading.

Many works [22], [26] are dedicated to the study of loads on the bearing systems of the machine tools and cutting tools, in which the differential equations of motion of these elements, solved by numerical method, are presented. Graphs of oscillations of the generalized coordinates of the tool, constructive elements of the machine tool are resulted. Examples of dynamic models are presented in the Fig. 1.4.

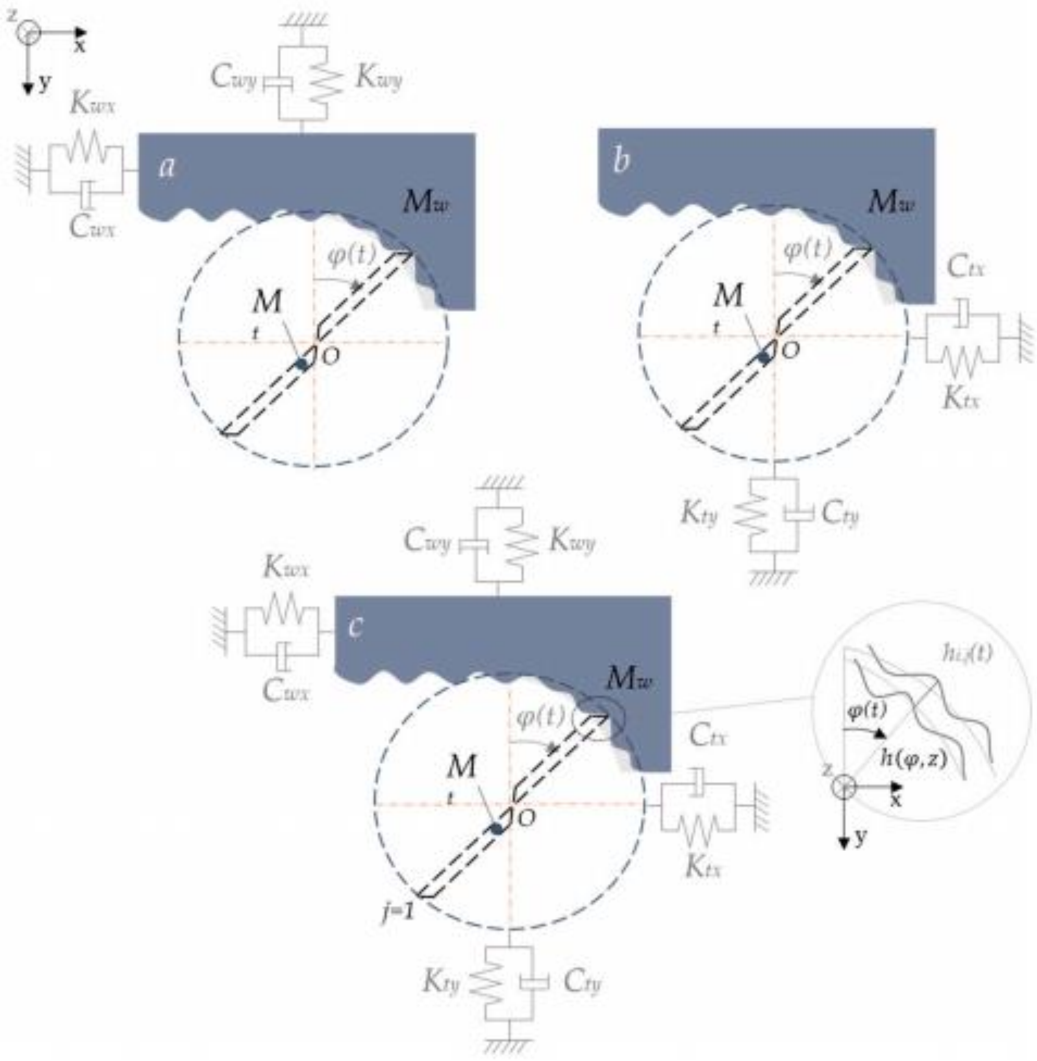


Figure 1.4 - Examples of models for studying of the dynamics of the thin-walled elements of workpieces machining [25]

Machining of intermittent thin-walled elements refers to transient dynamic processes. Solving the problem of detecting the actual loads on the thin-walled elements of the workpieces, on the fixtures and the power drive of the machine tool during the transition process, taking into account oscillations, is one of the important problems of the theory of these elements calculation.

The study of the parts of a dynamic system by isolating them from the circuit can not give a sufficiently accurate idea about the actual stresses in the components of the system machine tool-fixture-cutting tool-part. Therefore, the calculation of the system of interconnected parts must be carried out taking into account the elasticity of their connections, and hence the oscillating motion of all its elements.

The main directions of research are analytical and with using of the finite element method and appropriate software. In the study of the process of the thin-walled elements milling (Fig. 1.5) on the basis of the scheme of Fig. 1.6 the relationship between the normal force applied to the workpiece and the amount of deformation of the thin-walled element is established [27]:

$$F = \frac{E}{1-\mu^2} f\left(a,b,c\right)\left(w+\Delta w\left(u,v\right)\right)^3. \tag{1.1}$$

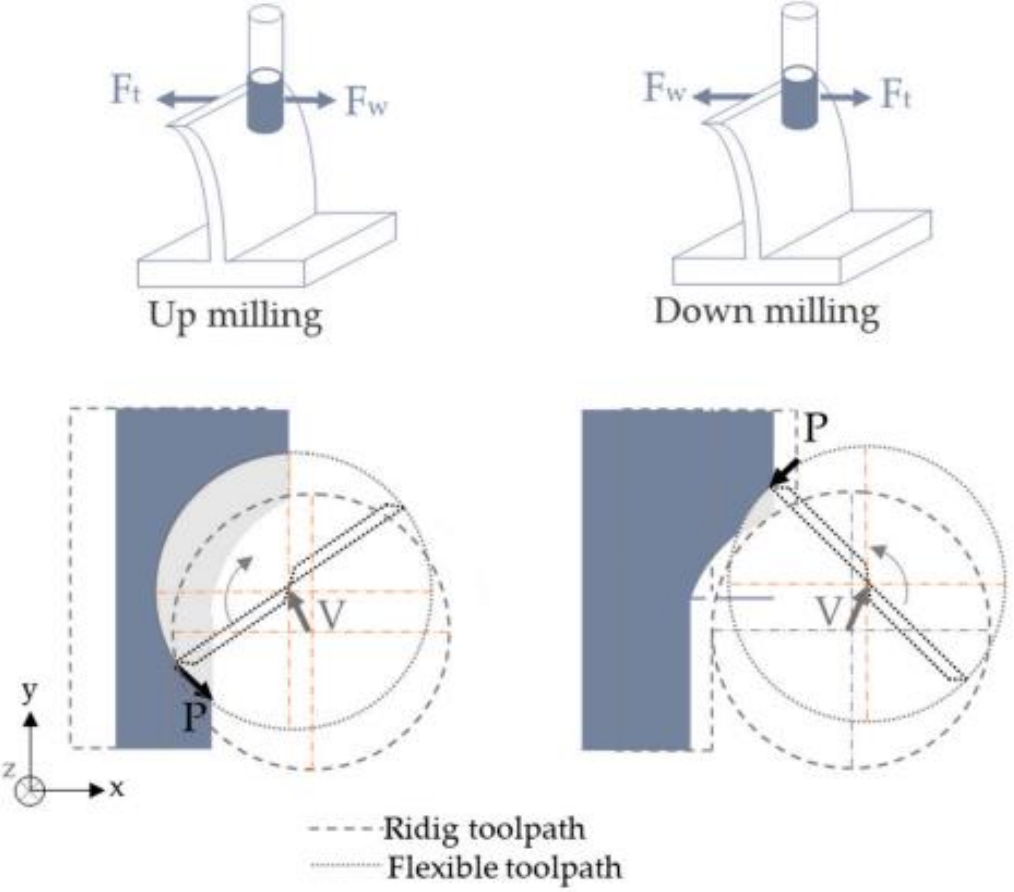


Figure 1.5 - Schemes of the thin-walled elements milling process research [25]

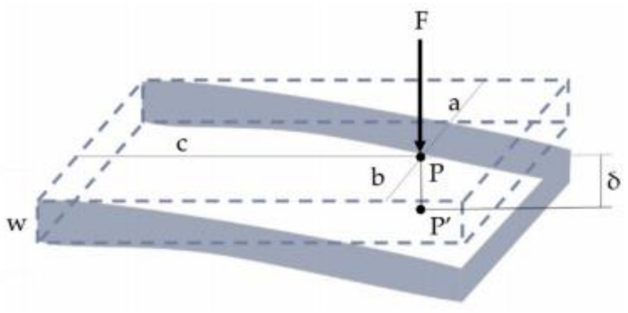


Figure 1.6 – The scheme of the thin-walled element deformation [27]

The examples of the finite element method using with the appropriate software in the study of the machining process of thin-walled elements of the workpiece are presented in Figure 1.7.

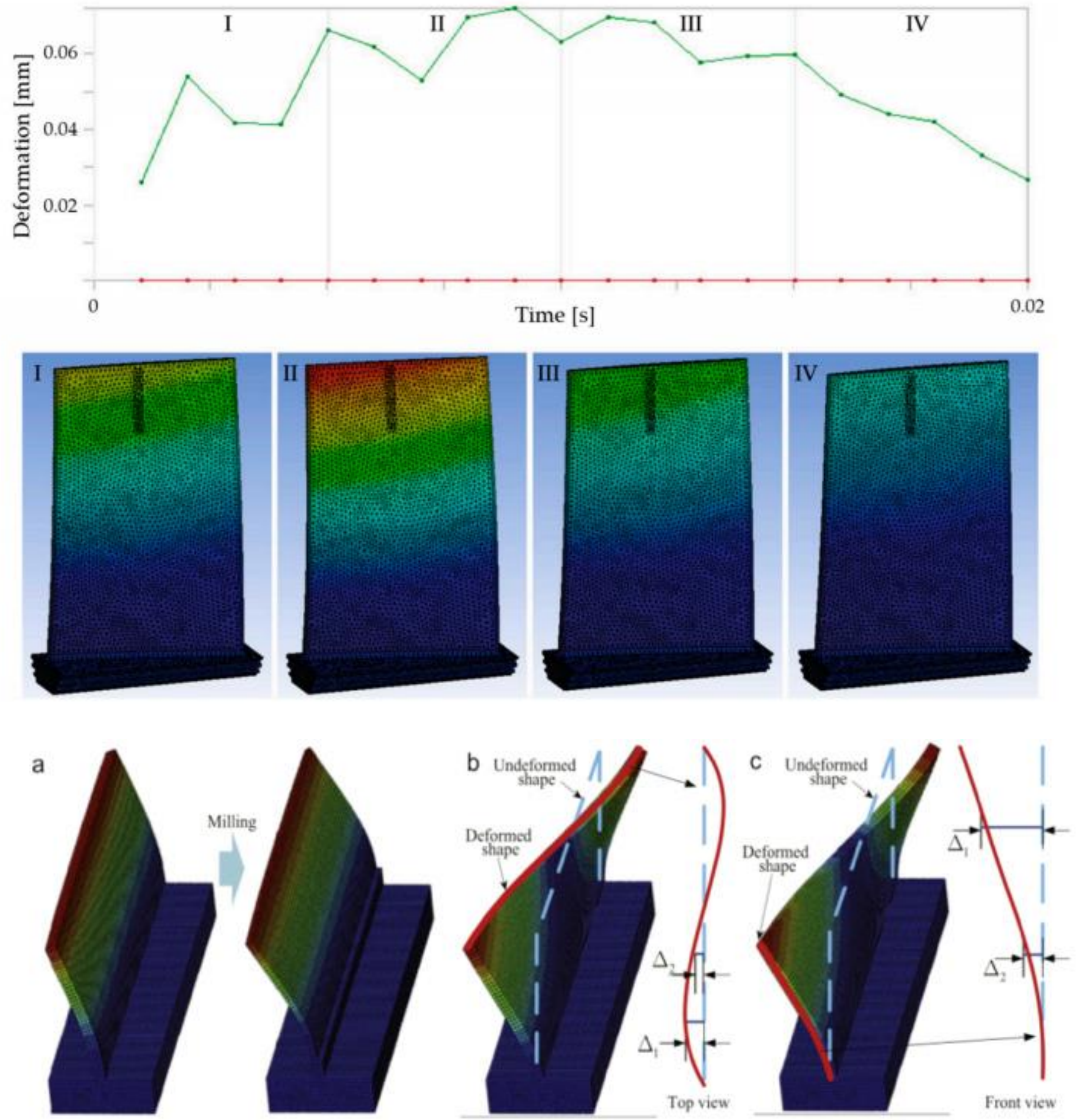


Figure 1.7 – The study of the thin-walled elements of the workpiece deformation during machining using the finite element method [28], [29]

1.2. Service purpose of the part

The part "Body structure" 732141.147 is the design element of the lamp used for lighting of industrial buildings. It is made by a casting method from aluminum alloy AK12.

The main surfaces of the part include the following surfaces: internal cylindrical surface $\varnothing 173H9(^{+0.1})$; Ra2.5, which is designed to install the ring; end surface $68h14(_{-0/74})$; Ra12.5 is intended for the accurate fitting of the combined parts (cases, rings); three internal radial surfaces R16.4 ± 0.1; Ra12.5 - for installation of locks; all threaded holes M4-7H; Ra6.3 - attachment holes.

The results of the technical requirements analysis for the part are presented in the table 1.1.

Table 1.1 - Analysis of technical requirements

Surface number	Surface name	Surface finish	Surfaces roughness
1	End face 68	Not machined	Rz50
2,8	Trough hole $\varnothing 3.3H12(^{+0.12})$ for thread M4-7H, L=7	12	Ra6.3
5, 17	Trough hole $\varnothing 3.3H12(^{+0.12})$ for thread M4-7H, L=5.5	12	Ra6.3
11, 14	Trough hole $\varnothing 3.3H12(^{+0.12})$ for thread M4-7H, L=6.5	12	Ra6.3
29, 32	Blind hole $\varnothing 3.3H12(^{+0.12})$ for thread M4-7H, L=8	12	Ra6.3
3,6,9,12, 15,18,30, 33	Internal chamfer 0.5×45°	14	Ra12.5
4, 9	Internal thread surface M4-7H, L=7	12	Ra6.3
7,19	Internal thread surface M4-7H, L=5.5	12	Ra6.3
13,16	Internal thread surface M4-7H, L=6.5	12	Ra6.3
31,34	Internal thread surface M4-7H, L=6	12	Ra6.3

Continuation of table 1.1

20,21	Hole $\varnothing 12H14(^{+0.43})$, L=2.5	14	Ra12.5
22-24	Internal radial surface R16.4±0.1; 92±0.1; $7.1^{+0.2}$; 8.3±0.1	14	Ra12.5
25,26,27	Hole $\varnothing 6H14(^{+0.3})$, L=11	14	Ra12.5
35	End face $68h14(_{-0.74})$	14	Ra12.5
36	Internal end face 8±0.1	14	Ra12.5
37	Internal cylindrical surface $\varnothing 173H9(^{+0.1})$	9	Ra2.5

1.3. Conclusions and tasks

As a result of the analysis of literature sources it is established, that parts with thin-walled elements obtained by machining on modern machine tools are widely used in various industries. Vibrations occur when machining such parts. This degrades the roughness of the machined surfaces and leads to the decrease in dimensional accuracy. Achieving low surface roughness is very important for such parts.

The existence of vibrations during parts machining not only reduces the tool life, but also leads to increased wear of the machine tool spindle unit. Also, due to the elastic deformation of the part, the defined allowance is not completely cut, leading to deviations in the shape and location of the nominal profile.

To reduce the vibrations of thin-walled elements during machining include methods: the use of step-by-step machining with alternate removal of allowance on each side of the thin-walled part; making the last pass without setting the allowance; forecasting of machining conditions by the method of petal diagrams (stability diagrams); application of cutting tools with variable geometry; application of modulation for the main movement speed; increasing the rigidity of thin-walled elements of parts through the use of special technological environments, etc.

The peculiarity of the thin-walled elements turning is that in the process of cutting there are impact loads and deformations of the workpiece material. Therefore, the study of the dynamics of such process is the actual task.

The following tasks must be solved in the qualification work:

1. Study of the dynamics of the cylindrical workpiece with thin-walled ribbed elements turning.
2. Development of the idealized mechanical model, which includes the workpiece with thin-walled ribbed elements, the lathe cutter, the clamping chuck, the machine tool spindle and the tool holder.
3. Derive and solve by numerical method the system of differential equations describing the vibrations of the elements of the equivalent multi-mass system for the cylindrical workpiece with thin-walled ribbed elements turning process.
4. Carry out experimental studies to determine the roughness of thin-walled ribbed elements after turning in workpieces from steel 45 depending on changes in three main factors: cutter feed, depth of cut and thickness of thin-walled ribbed element.
5. Improve the existing technological process of the "Body structure" 732141.147 production.

2 SCIENTIFIC AND RESEARCH PART

2.1. The study of the cylindrical part with thin-walled elements turning dynamics

Modern technical systems, as well as production make higher demands on the quality of machine parts surfaces. When manufacturing cylindrical parts with thin-walled ribbed elements by casting and volume plastic deformation methods, the required accuracy of their dimensions is not always ensured.

Therefore, it is actual to use the turning operation for thin-walled ribbed elements of cylindrical parts in the technological process of their manufacture.

Specifics of the cylindrical parts with thin-walled ribbed elements geometry have a significant influence on the dynamics of their turning, as well as on the design of the necessary fixtures and tools. Turning of external diameters of cylindrical parts with thin-walled ribbed elements can be carried out by straight cutters as well as for normal cylindrical surfaces. However, this process has significant differences.

First, thin-walled ribbed elements of cylindrical parts are characterized by relatively low stiffness, and secondly, they are intermittent surfaces. Therefore, the process of their turning is related with extremely complex impact and forming processes. As a result, there is the need to develop the mathematical model that would show the nature of changes in loads on the workpiece, cutter, chuck and machine tool elements.

Peculiarities of the mutual influence of thin-walled ribbed elements of the cylindrical workpiece and the lathe cutter originate the preconditions for studying the dynamics of such structural elements turning.

The process of thin-walled ribbed elements of the cylindrical workpiece turning is characterized by changes in the force parameters of the process over time, in particular with the occurrence of impact loads. Therefore, such turning is associated with complex processes of interaction between the workpiece and the cutter and this process can be investigated by forming the dynamic model that determines the deformation of the elements of a somewhat idealized given system, which includes the following elements: workpiece with thin-walled ribbed elements, straight cutter, clamping machine chuck, machine tool spindle, tool holder.

The process of thin-walled ribbed elements of the cylindrical workpiece turning can be attributed to the transitional dynamic processes. The given system (Fig. 2.1), which includes: workpiece with thin-walled ribbed elements, lathe straight cutter, clamping chuck, machine tool spindle, tool holder has been replaced by an idealized mechanical model consisting of concentrated masses.

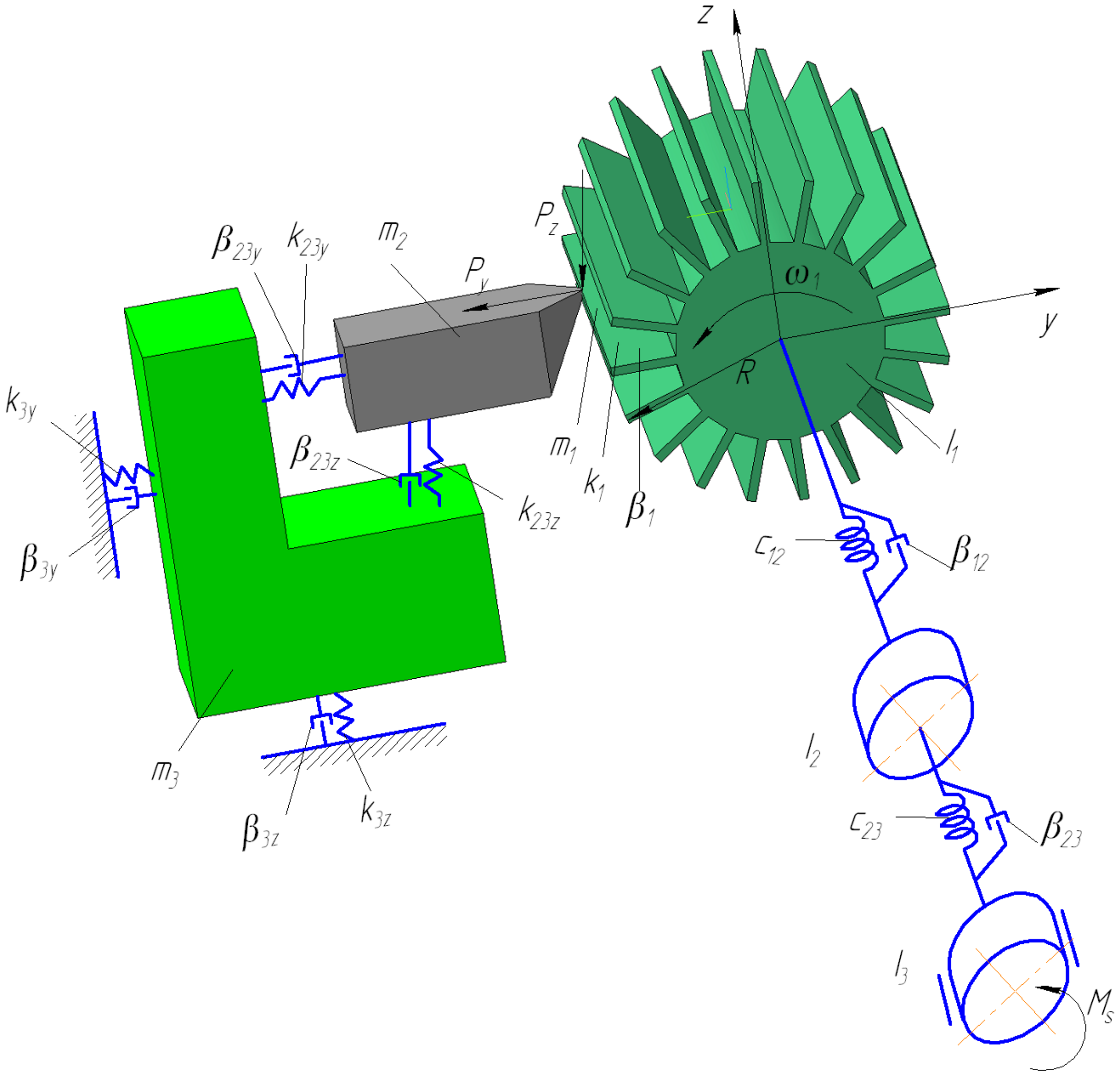


Figure 2.1 - The scheme of the idealized system for studying of the thin-walled ribbed elements of the cylindrical workpiece turning dynamics

Such masses are connected by elastic bonds with constant stiffness coefficients over time.

Figure 2.1 shows the masses of the idealized system elements for studying the dynamics of thin-walled ribbed elements of the cylindrical workpiece turning: I_1 - moment of inertia of the workpiece with thin-walled ribbed elements; I_2 - the given moment of inertia of the machine tool clamping chuck; I_3 - the given moment of inertia of the machine tool spindle; m_1 - the mass of the thin-walled ribbed element; m_2 - the mass of the lathe straight cutter; m_3 - the mass of the tool holder.

Figure 2.1 also shows the given stiffness coefficients and damping coefficients: C_{12} - the given stiffness of the connection between the workpiece with thin-walled ribbed elements and the machine tool clamping chuck; C_{23} - the given stiffness of the connection between the machine tool clamping chuck and the machine tool spindle; k_1 - the linear stiffness of the thin-walled ribbed element; k_{23z}, k_{23y} - the given linear stiffnesses of the lathe straight cutter in the directions of the *z* and *y* axes respectively; k_{3z}, k_{3y} - the given linear stiffnesses of the tool holder in the directions of the *z* and *y* axes respectively.

Figure 2.1 also shows the following damping coefficients: β_{12} - the damping coefficient between the workpiece with thin-walled ribbed elements and the machine tool clamping chuck; β_{23} - the damping coefficient between the machine tool clamping chuck and the machine tool spindle; β_1 - the damping coefficient of the thin-walled ribbed element vibrations; β_{23z}, β_{23y} - the damping coefficients of the lathe straight cutter vibrations in the directions of the *z* and *y* axes respectively; β_{3z}, β_{3y} - the damping coefficients of the tool holder vibrations in the directions of the *z* and *y* axes respectively.

The tangential cutting force $P_z(t)$, the radial cutting force $P_y(t)$ and the torque $M = P_z(t) \cdot R$ (where R - radius of thin-walled ribbed elements turning) is applied to the workpiece with thin-walled ribbed elements clamped in the machine tool chuck during turning.

The tangential cutting force $P_z(t)$, and the radial cutting force $P_y(t)$ are applied on the lathe straight cutter with the mass m_2.

During the workpiece surfaces turning the change in cutting force is approximated in the form of a sinusoid. Accordingly, the tangential cutting force $P_z(t)$ and the radial cutting force $P_y(t)$ periodically increase to the maximum value and then decrease to the minimum value. The maximum values of the tangential and radial cutting forces depending on the cutting conditions are determined by known empirical equations [20]:

$$P_z = 10 \cdot C_{Pz} \cdot t_P^x \cdot S^y \cdot V^n \cdot K_z, \tag{2.1}$$

$$P_y = 10 \cdot C_{Py} \cdot t_P^x \cdot S^y \cdot V^n \cdot K_y, \tag{2.2}$$

where the depth of cut t_P, feed rate S, cutting speed V, power and correction factors obtained as a result of experimental studies are taken into account.

Also, the change in the cutting force can be represented by:

$$P_z(t) = P_{z\max} \cdot \sin\left(\frac{\pi}{t_k} t\right), \tag{2.3}$$

where t_k is the time during which contact occurs between the cutter and the thin-walled ribbed element.

The condition $P_z(t) = 0$ is satisfied if $t < t_k$.

Changing of the cutting force in contact with the next thin-walled ribbed element:

$$P_z(t) = P_{z\max} \cdot \sin\left(\frac{\pi}{t_k} t - \frac{(i-1)\pi t_1}{t_k}\right), \tag{2.4}$$

where i is the ordinal number of the thin-walled ribbed element;

t_1 - time during which cutting does not occur.

The valid condition $P_{z\max} = 0$, if $t < it_1$ and $t > it_1 + t_k$.

The angles of rotation φ_1, φ_2, φ_3 and the linear displacements z_1, z_2, z_3, y_1, y_2, y_3 of the elements of the idealized system are selected as the calculated generalized coordinates.

The kinetic energy of the given mechanical system:

$$T = \frac{I_1 \cdot \dot{\varphi}_1^2}{2} + \frac{I_2 \cdot \dot{\varphi}_2^2}{2} + \frac{I_3 \cdot \dot{\varphi}_3^2}{2} + \frac{m_1 \cdot \dot{z}_1^2}{2} + \frac{m_2 \cdot \dot{z}_2^2}{2} + \\ + \frac{m_3 \cdot \dot{z}_3^2}{2} + \frac{m_2 \cdot \dot{y}_2^2}{2} + \frac{m_3 \cdot \dot{y}_3^2}{2}. \tag{2.5}$$

The potential energy of the given mechanical system:

$$\varPi = \frac{C_{12} \cdot (\varphi_1 - \varphi_2)^2}{2} + \frac{C_{23} \cdot (\varphi_2 - \varphi_3)^2}{2} + \frac{k_1 \cdot (R\varphi_1 - z_1)^2}{2} + \frac{k_{23z} \cdot (z_3 - z_2)^2}{2} + \\ + \frac{k_{3z} \cdot z_3^2}{2} + \frac{k_{23y} \cdot (y_3 - y_2)^2}{2} + \frac{k_{3y} \cdot y_3^2}{2}. \tag{2.6}$$

The scattering function of the given mechanical system:

$$\varPhi = \frac{\beta_{12} \cdot (\dot{\varphi}_1 - \dot{\varphi}_2)^2}{2} + \frac{\beta_{23} \cdot (\dot{\varphi}_2 - \dot{\varphi}_3)^2}{2} + \frac{\beta_1 \cdot (R\dot{\varphi}_1 - \dot{z}_1)^2}{2} + \frac{\beta_{23z} \cdot (\dot{z}_3 - \dot{z}_2)^2}{2} + \\ + \frac{\beta_{3z} \cdot \dot{z}_3^2}{2} + \frac{\beta_{23y} \cdot (\dot{y}_3 - \dot{y}_2)^2}{2} + \frac{\beta_{3y} \cdot \dot{y}_3^2}{2}. \tag{2.7}$$

The Lagrange's equation to determine the vibrations of the elements of the given system:

- torsion:

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{\varphi}_n} + \frac{\partial \varPi}{\partial \varphi_n} + \frac{\partial \varPhi}{\partial \dot{\varphi}_n} = P_z(t) \cdot R. \tag{2.8}$$

- linear:

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{z}_n}+\frac{\partial \Pi}{\partial z_n}+\frac{\partial \Phi}{\partial \dot{z}_n}=P_z(t), \tag{2.9}$$

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{y}_n}+\frac{\partial \Pi}{\partial y_n}+\frac{\partial \Phi}{\partial y_n}=P_y(t). \tag{2.10}$$

On the basis of equations (2.8), (2.9) and (2.10) the system of differential equations is derived, which describes the vibrations of the elements of the equivalent multimass system of Fig. 2.1:

$$\left.\begin{aligned}
&I_1\cdot\ddot{\varphi}_1+C_{12}\cdot\left(\varphi_1-\varphi_2\right)+\beta_{12}\left(\dot{\varphi}_1-\dot{\varphi}_2\right)+k_1\left(R\varphi_1-z_1\right)R+\beta_1\left(R\dot{\varphi}_1-\dot{z}_1\right)R=-P_z(t)R;\\
&I_2\cdot\ddot{\varphi}_2+C_{12}\cdot\left(\varphi_2-\varphi_1\right)+\beta_{12}\left(\dot{\varphi}_2-\dot{\varphi}_1\right)+C_{23}\cdot\left(\varphi_2-\varphi_3\right)+\beta_{23}\left(\dot{\varphi}_2-\dot{\varphi}_3\right)=0;\\
&I_3\cdot\ddot{\varphi}_3+C_{23}\cdot\left(\varphi_3-\varphi_2\right)+\beta_{23}\left(\dot{\varphi}_3-\dot{\varphi}_2\right)=M_s;\\
&m_1\cdot\ddot{z}_1-k_1\left(R\varphi_1-z_1\right)-\beta_1\left(R\dot{\varphi}_1-\dot{z}_1\right)=P_z(t);\\
&m_2\cdot\ddot{z}_2+k_{23z}\cdot\left(z_2-z_3\right)+\beta_{23z}\cdot\left(\dot{z}_2-\dot{z}_3\right)=P_z(t);\\
&m_3\cdot\ddot{z}_3+k_{23z}\cdot\left(z_3-z_2\right)+\beta_{23z}\cdot\left(\dot{z}_3-\dot{z}_2\right)+k_{3z}\cdot z_3+\beta_{3z}\cdot\dot{z}_3=0;\\
&m_2\cdot\ddot{y}_2+k_{23y}\cdot\left(y_2-y_3\right)+\beta_{23y}\cdot\left(\dot{y}_2-\dot{y}_3\right)=P_y(t);\\
&m_3\cdot\ddot{y}_3+k_{23y}\cdot\left(y_3-y_2\right)+\beta_{23y}\cdot\left(\dot{y}_3-\dot{y}_2\right)+k_{3y}\cdot y_3+\beta_{3y}\cdot\dot{y}_3=0.
\end{aligned}\right\} \tag{2.11}$$

where M_s – the torque on the machine tool spindle.

To solve the system of equations (2.11), the boundary conditions at the time of contact between the lathe cutter and the thin-walled ribbed element of the workpiece are accepted, while for the time $t=0$ for numerical calculation, the initial conditions are accepted [22]:

$$\begin{gathered}
\varphi_1(0)=0,\ \varphi_2(0)=0,\ \varphi_3(0)=0,\ z_1(0)=0,\ z_2(0)=0,\ z_3(0)=0,\\
y_2(0)=0,\ y_3(0)=0,\\
\dot{\varphi}_1(0)=0,\ \dot{\varphi}_2(0)=0,\ \dot{\varphi}_3(0)=0,\ \dot{z}_1(0)=0,\ \dot{z}_2(0)=0,\ \dot{z}_3(0)=0,\\
\dot{y}_2(0)=0,\ \dot{y}_3(0)=0.
\end{gathered} \tag{2.12}$$

The solution of the system of differential equations (2.11) is performed using application software that uses the subroutine of the Runge-Kutta numerical method with initial coordinates determined from equations (2.12). The solution is presented in the form of numerical data and graphs.

As a result of using the developed algorithm and subroutine, graphs are constructed showing the dependences of change: tangential cutting force on a thin-walled ribbed element in time for the workpiece rotational speeds 1200 rpm (Fig. 2.2) and 600 rpm (Fig. 2.5), thin-walled ribbed element deformation in time at 1200 rpm (Fig. 2.3) and at 600 rpm (Fig. 2.6), the deformation rate of the thin-walled ribbed element in time at 1200 rpm (Fig. 2.4), the deformation of the cutter in time (Fig. 2.7), the deformation rate of the cutter in time (Fig. 2.8), the deformation of the workpiece in time (Fig. 2.9).

The components of the system of equations (2.11) were determined on the basis of analytical methods and also on the basis of experimental research data on the given stiffness coefficients and damping coefficients. Based on the constructed graphs (Fig. 2.3, Fig. 2.6) it is established that the deformations of the thin-walled ribbed element in time have a variable character with a sharp increase at the time of impact with the cutter. After the impact, the oscillations of such element are damped.

The maximum deformation of the thin-walled ribbed element is 0.04 mm. The largest deformation of the cutter is 0.0065 mm. This difference is due to the fact that the stiffness of the cutter is higher than the stiffness of the thin-walled ribbed element.

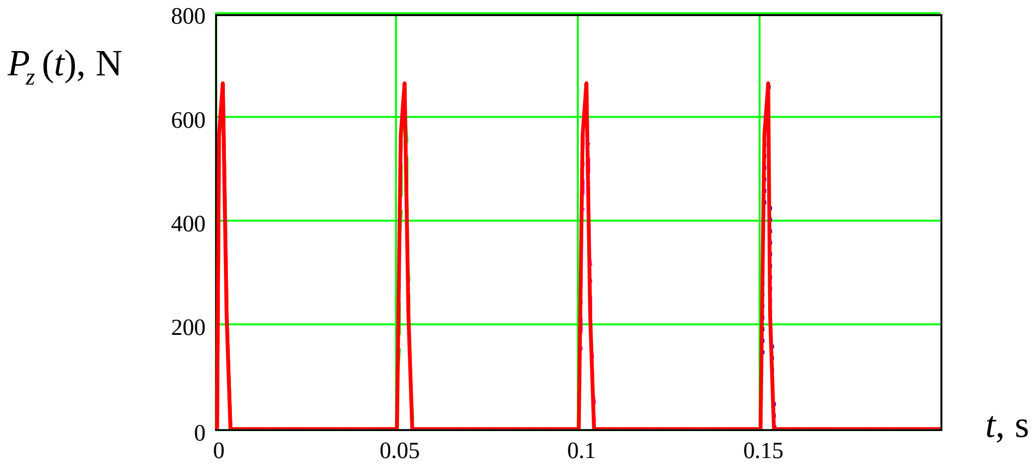


Figure 2.2 - Graph of the tangential cutting force on a thin-walled ribbed element change in the time at the rotational speed of the workpiece 1200 rpm

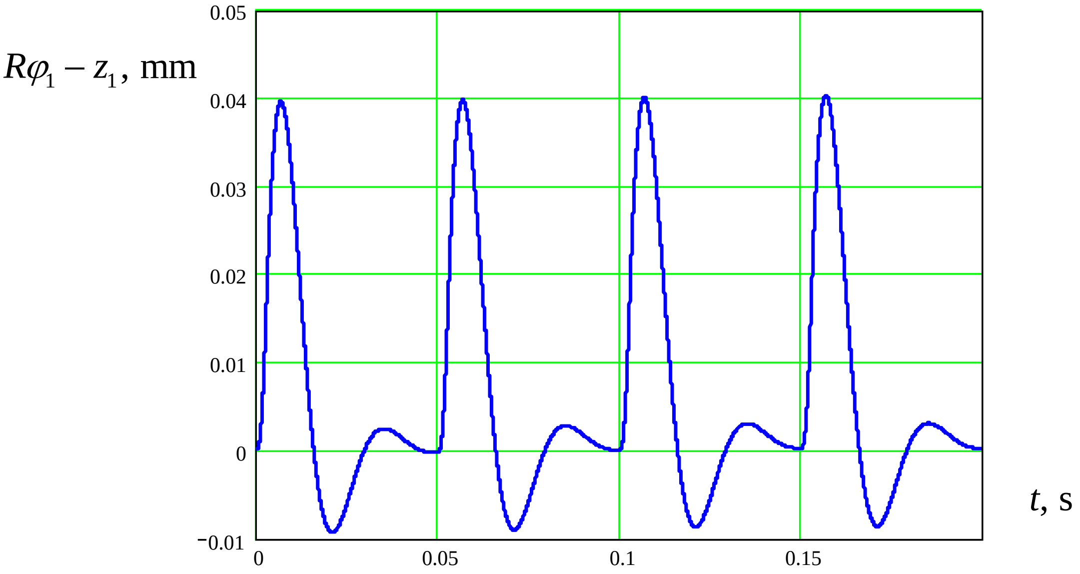


Figure 2.3 - Graph of the thin-walled ribbed element deformation changes in the time at the rotational speed of the workpiece 1200 rpm

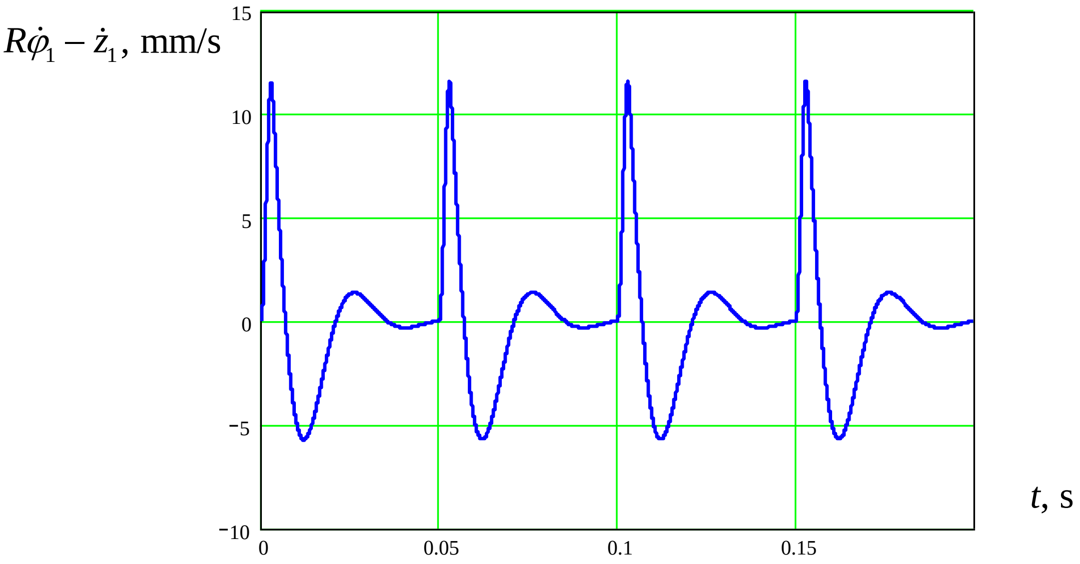


Figure 2.4 - Graph of the thin-walled ribbed element deformation rate changes in the time at the rotational speed of the workpiece 1200 rpm

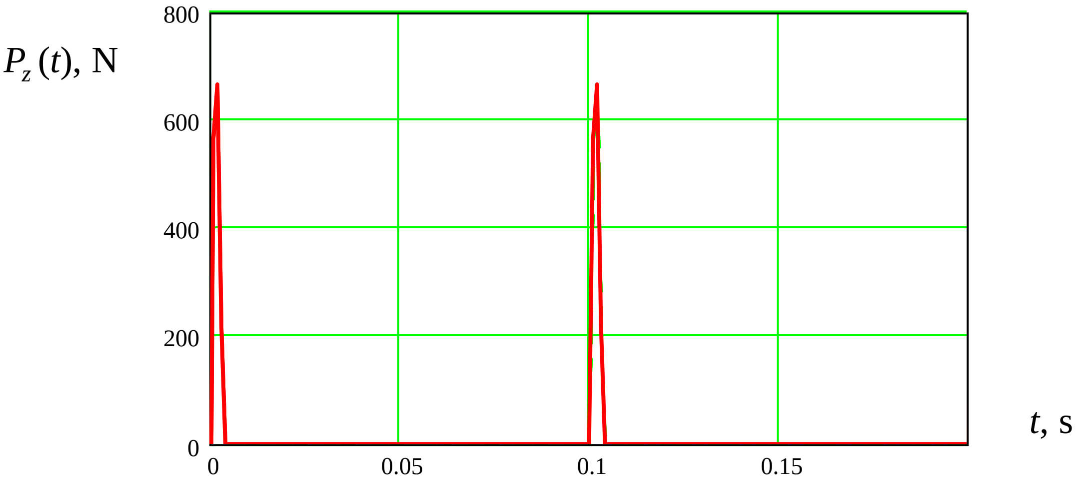


Figure 2.5 - Graph of the tangential cutting force on a thin-walled ribbed element change in the time at the rotational speed of the workpiece 600 rpm

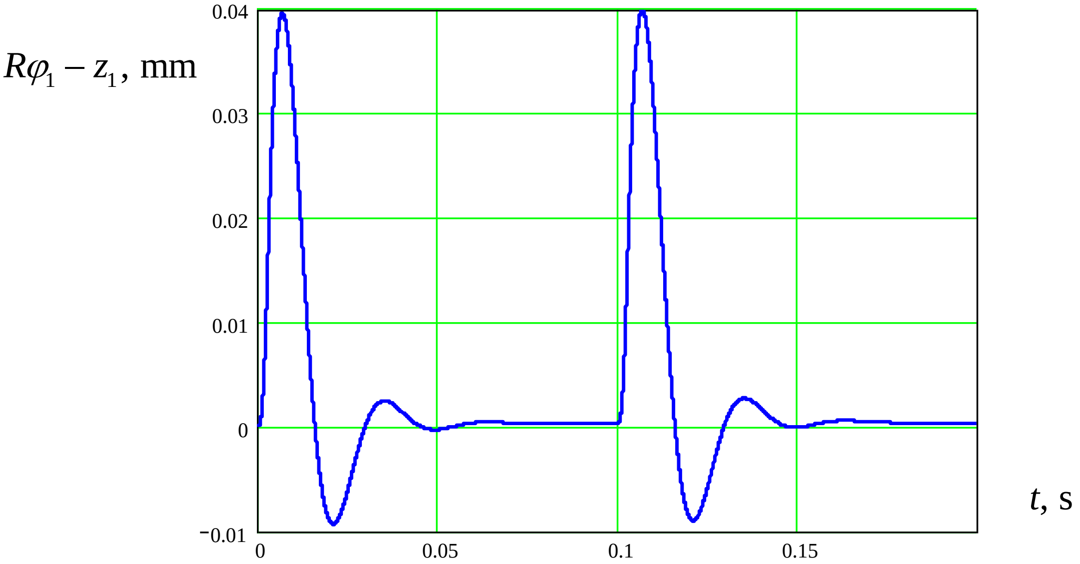


Figure 2.6 - Graph of the thin-walled ribbed element deformation changes in the time at the rotational speed of the workpiece 600 rpm

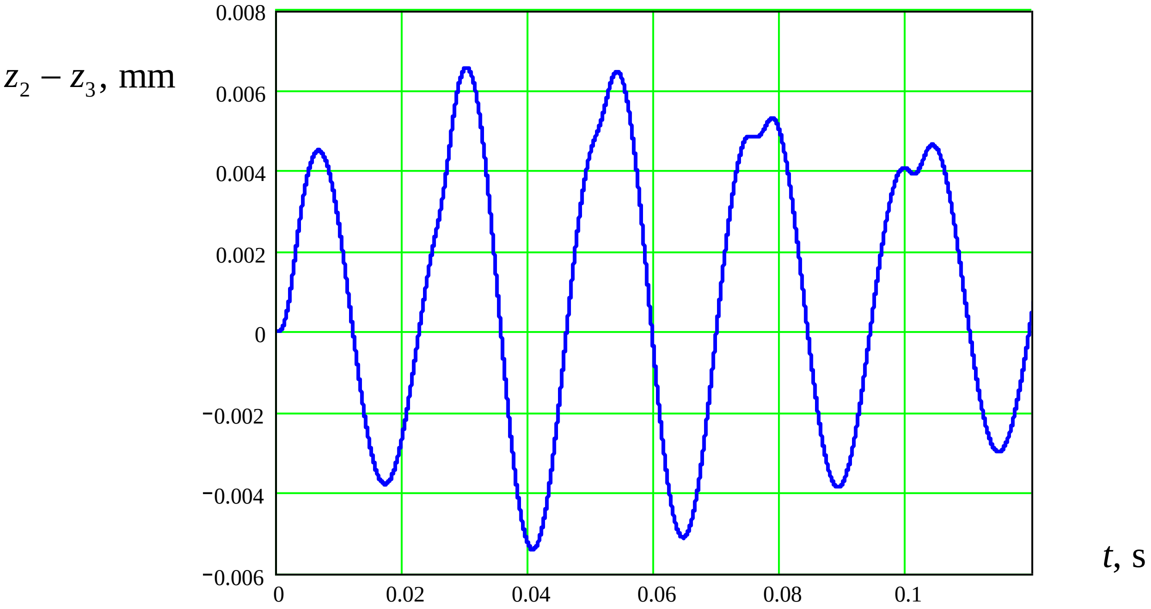


Figure 2.7 - Graph of the cutter deformation change in the time

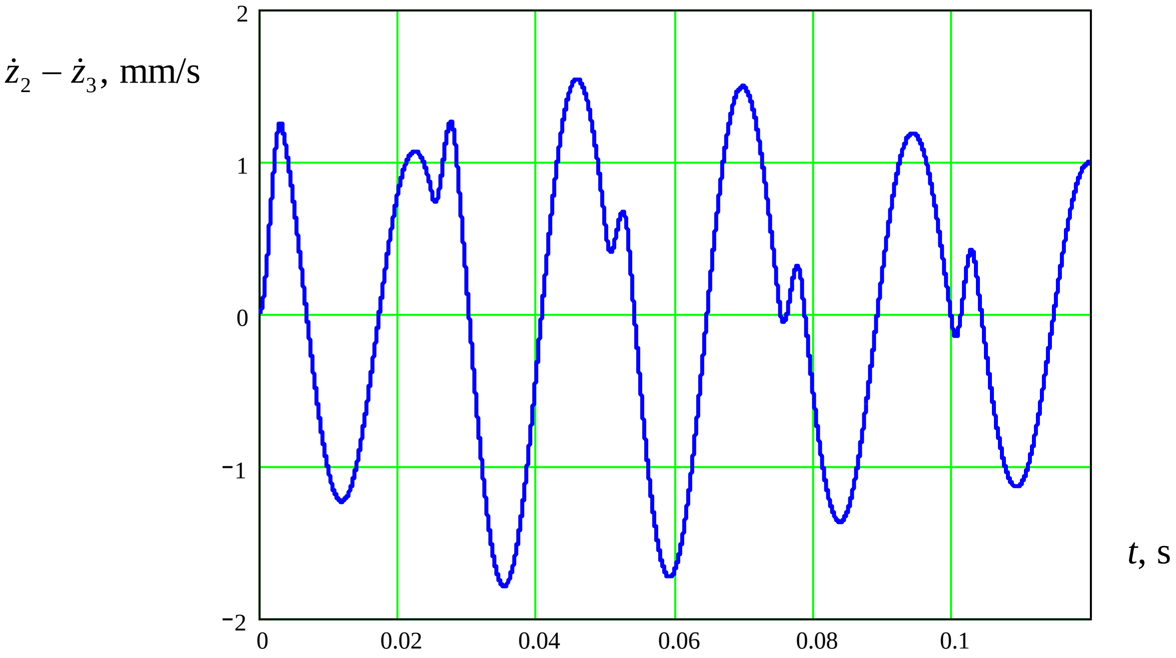


Figure 2.8 - Graph of the cutter deformation rate change in the time

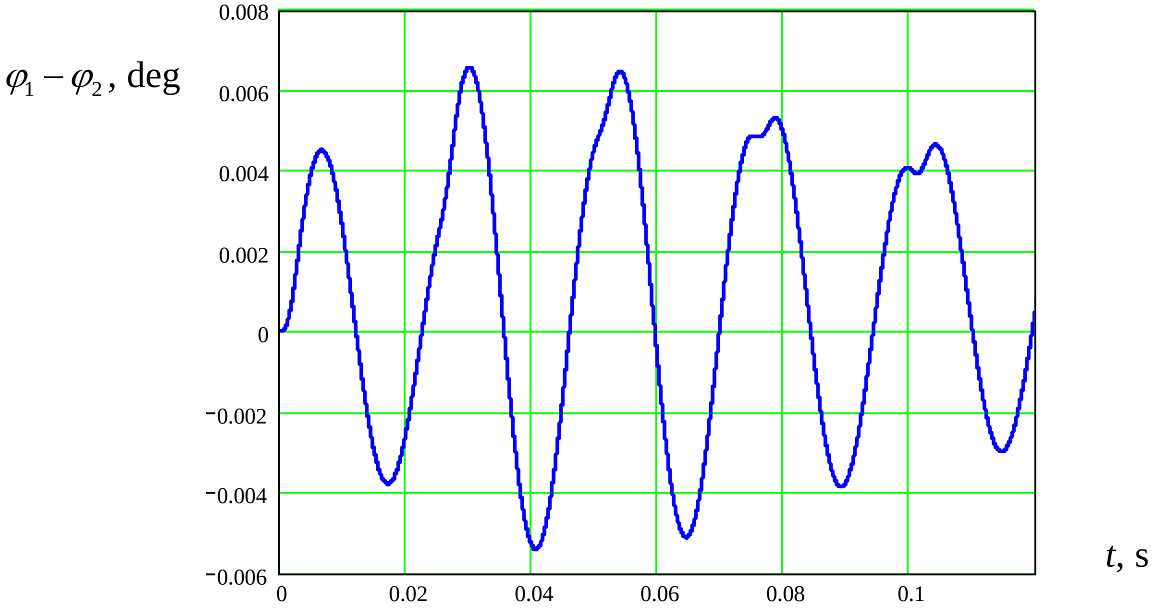


Figure 2.7 - Graph of the workpiece deformation change in the time

2.2. The results of experimental studies of the thin-walled ribbed elements roughness on the workpiece after turning

The qualification work presents the results of experimental studies of the thin-walled ribbed elements roughness on the workpiece after turning.

The study included the following stages:

1. The choice of the lathe, the workpieces with thin-walled ribbed elements to be turned, means of the turned surface roughness measuring.

2. Conducting experimental studies to determine the roughness of thin-walled ribbed elements after turning in steel workpieces 45 depending on the change of the three main factors: the cutter feed, depth of cut and thickness of thin-walled ribbed element.

The lathe, the cutter made of high-speed steel was used for thin-walled ribbed elements turning. The workpiece was clamped in a special chuck. The diameter of the turning was 100 mm.

The roughness of thin-walled rib elements after turning was determined on the basis of Talyrond trace and their statistical processing. Statistical processing of the obtained results was performed using application software.

To establish the influence of the main variables of the technological and design factors on the roughness (optimization parameter Ra) of the thin-walled ribbed elements after turning of the workpieces from steel 45 (independent factors), appropriate experimental studies were conducted. Factors are varied on three levels. Previous experiments have found that the main variables that affect the roughness of thin-walled ribbed elements after turning are: depth of cut t and thickness of thin-walled ribbed element h ie $Ra = f(S, t, h)$.

The function describing the dependence of the thin-walled ribbed elements roughness after turning is presented in the form of a second-order polynomial as a result of the experiment statistical data processing and determining the coefficients of the regression equation. The limit values of the experiment variables are presented in table 2.1, which includes

- the cutter feed S, which is encoded by the index x_1;
- the depth of cut t, which is encoded by the index x_2;
- the thickness of thin-walled ribbed element h, which is encoded by the index x_3.

Table 2.1 - Limit values of the experiment variables in the study of the thin-walled ribbed elements roughness after turning

Variable factors	Appellation		Interval variation	Levels of variation, natural (coded)		
	natural	Cod.				
The cutter feed	S, mm/rev	x_1	0.05	0.2 (+1)	0.15 (0)	0.1 (-1)
The depth of cut	t, mm	x_2	0.25	1 (+1)	0.75 (0)	0.5 (-1)
The thickness of thin-walled ribbed element	h, mm	x_3	0.2	1.4 (+1)	1.2 (0)	1 (-1)

The values of the regression equation coefficients are presented in table 2.2.

Table 2.2 – The values of regression equation coefficients

Coeff	b_0	b_1	b_2	b_3	b_{12}	b_{13}	b_{23}	b_{11}	b_{22}	b_{33}
Steel 45	5.911	0.437	0.204	-1.091	0.015	-0.078	-0.038	-0.056	-0.031	0.234

The general form of the regression equation of the thin-walled ribbed elements roughness after turning depending on the change: cutter feed S, depth of cut t and thickness of thin-walled ribbed element h, that is $Ra_{(x_1,x_2,x_3)} = f(S,t,h)$ according to experimental studies in coded values is equal to:

- during turning of thin-walled ribbed elements in workpieces from steel 45

$$\begin{aligned} Ra_{(x_1,x_2,x_3)} &= 5{,}911 + 0{,}437x_1 + 0{,}204x_2 - 1{,}091x_3 + 0{,}015x_1x_2 - \\ &-0{,}078x_1x_3 - 0{,}038x_2x_3 - 0{,}056x_1^2 - 0{,}031x_2^2 + 0{,}234x_3^2, \end{aligned} \tag{2.13}$$

where x_1 is the coded value of the cutter feed; x_2 - coded value of depth of cut; x_3 - coded value of the thickness of thin-walled ribbed element.

The derived coefficients of equation (2.13) are significant.

The regression equation (2.13) after transformations is presented in physical quantities:

- during turning of thin-walled ribbed elements in workpieces from steel 45

$$Ra_{(S,t,h)} = 16,22 + 23,29S + 2,292t - 17,76h + 1,2St - \\ -7,8Sh - 0,76th - 22,4S^2 - 0,496t^2 + 5,85h^2. \tag{2.14}$$

The obtained coded and natural regression equations (2.13) and (2.14) can be used to predict the roughness of thin-walled ribbed elements after turning in the following limit values of variable independent factors:

$$0.1 \le S \le 0.2 \ \ \text{(mm/rev)};\ 0.5 \le t \le 1 \ \ \text{(mm)};\ 1 \le h \le 1.4 \ \ \text{(mm)}.$$

The graphs of Figures 2.10 - 2.15 show the three-dimensional and two-dimensional dependences of the thin-walled ribbed elements roughness after turning in workpieces from steel 45.

From the obtained regression equations (2.13), (2.14) and graphs in Figures 2.10-2.15, it was concluded that the thickness of the thin-walled ribbed elements *h* has the greatest influence on the roughness *Ra* of thin-walled ribbed elements after turning, and the depth of cut *t* has the smallest influence. With increasing cutter feed *S* and depth of cut *t*, the roughness *Ra* of thin-walled ribbed elements after turning increases, and with increasing thickness of the thin-walled ribbed elements *h* - decreases.

The maximum value of the roughness *Ra* of thin-walled ribbed elements after turning is 7.92 µm, and the minimum is 4.76 µm. Increasing the cutter feed *S* from 0.1 mm/rev to 0.2 mm/rev leads to the increase in roughness *Ra* by 16%. Increasing the depth of cut *t* from 0.5 mm to 1 mm increases the roughness *Ra* by 7%, and increasing the thickness of the thin-walled ribbed elements *h* from 0.6 mm to 1 mm decreases the roughness *Ra* by 30%.

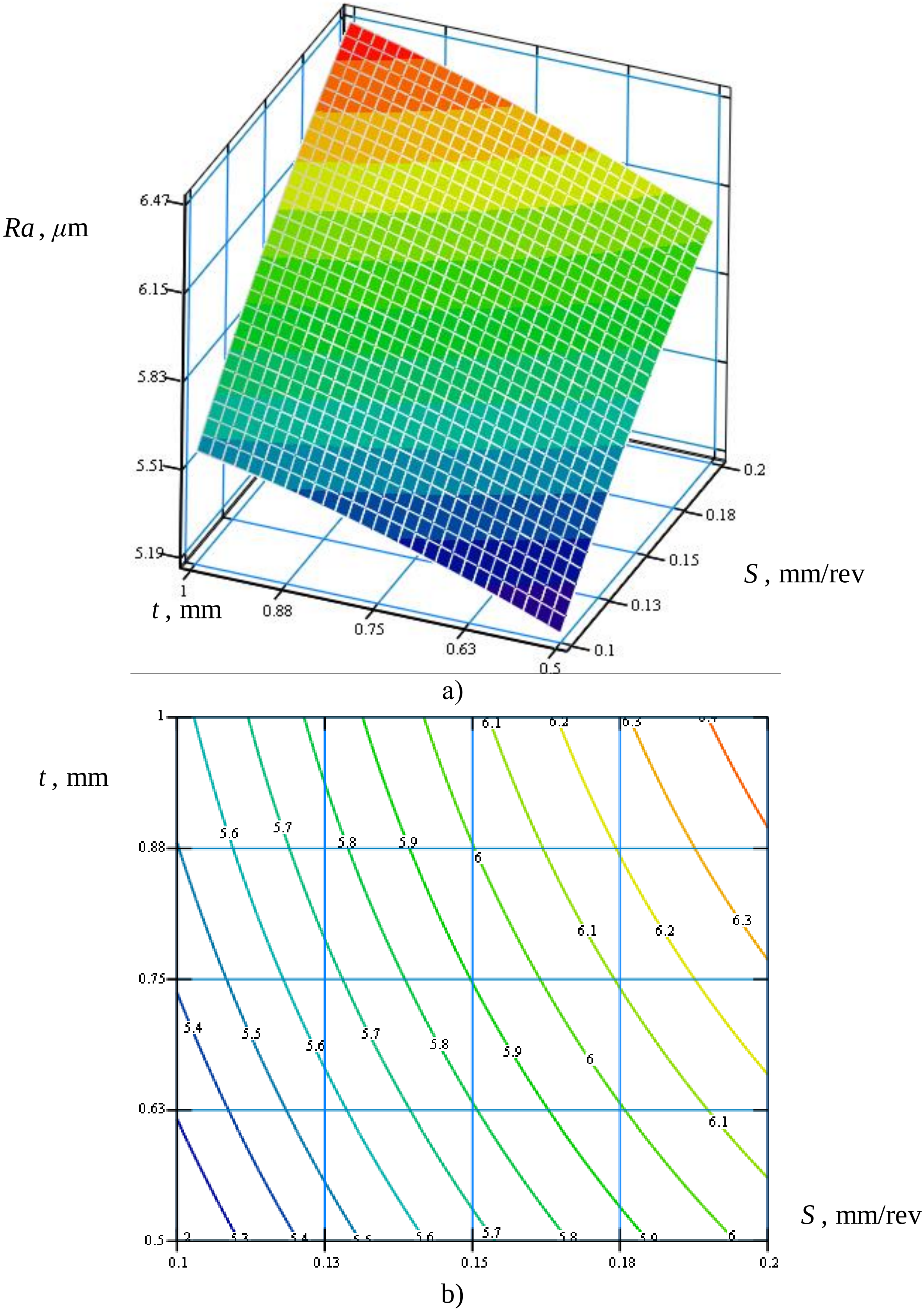
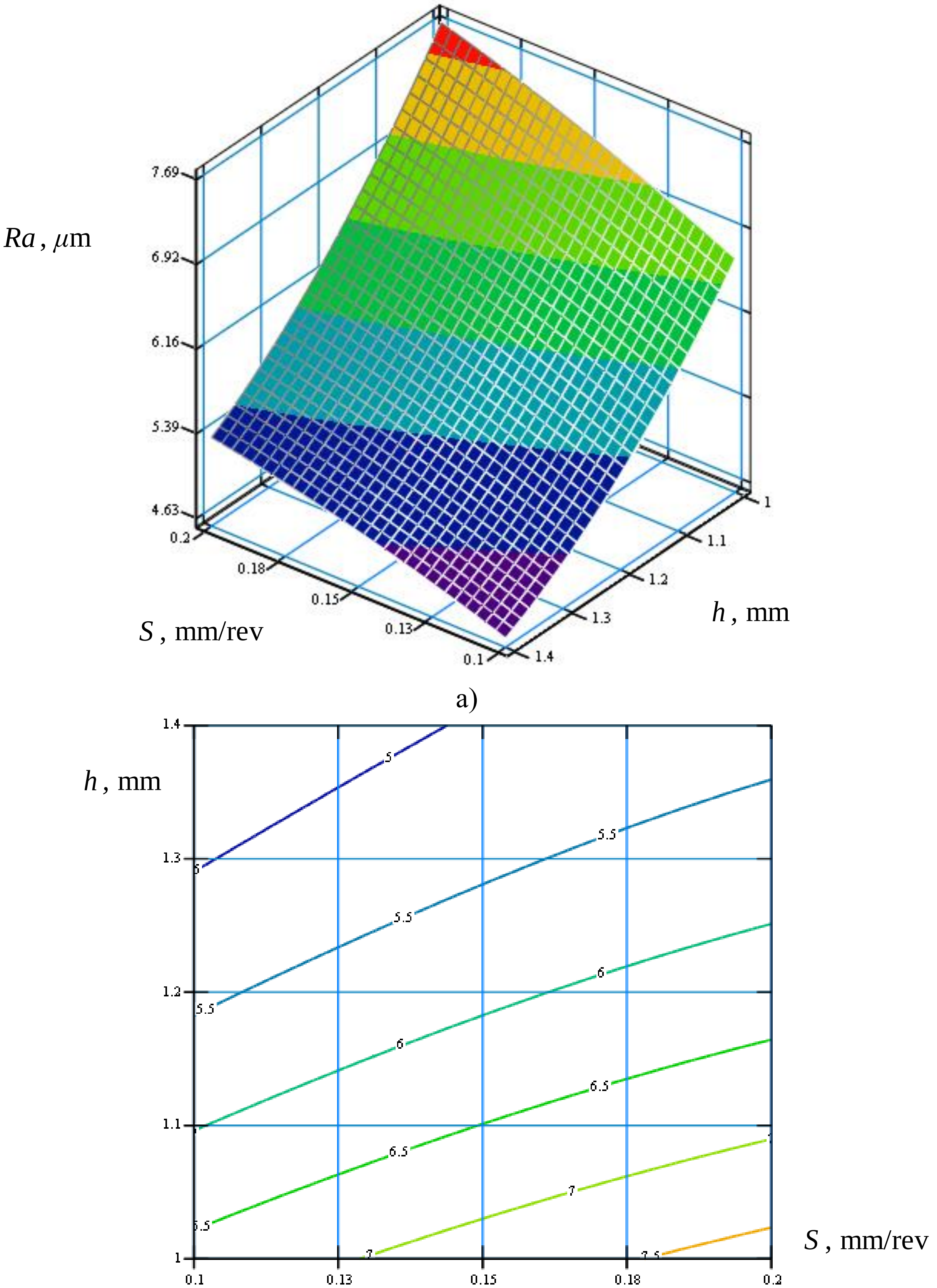


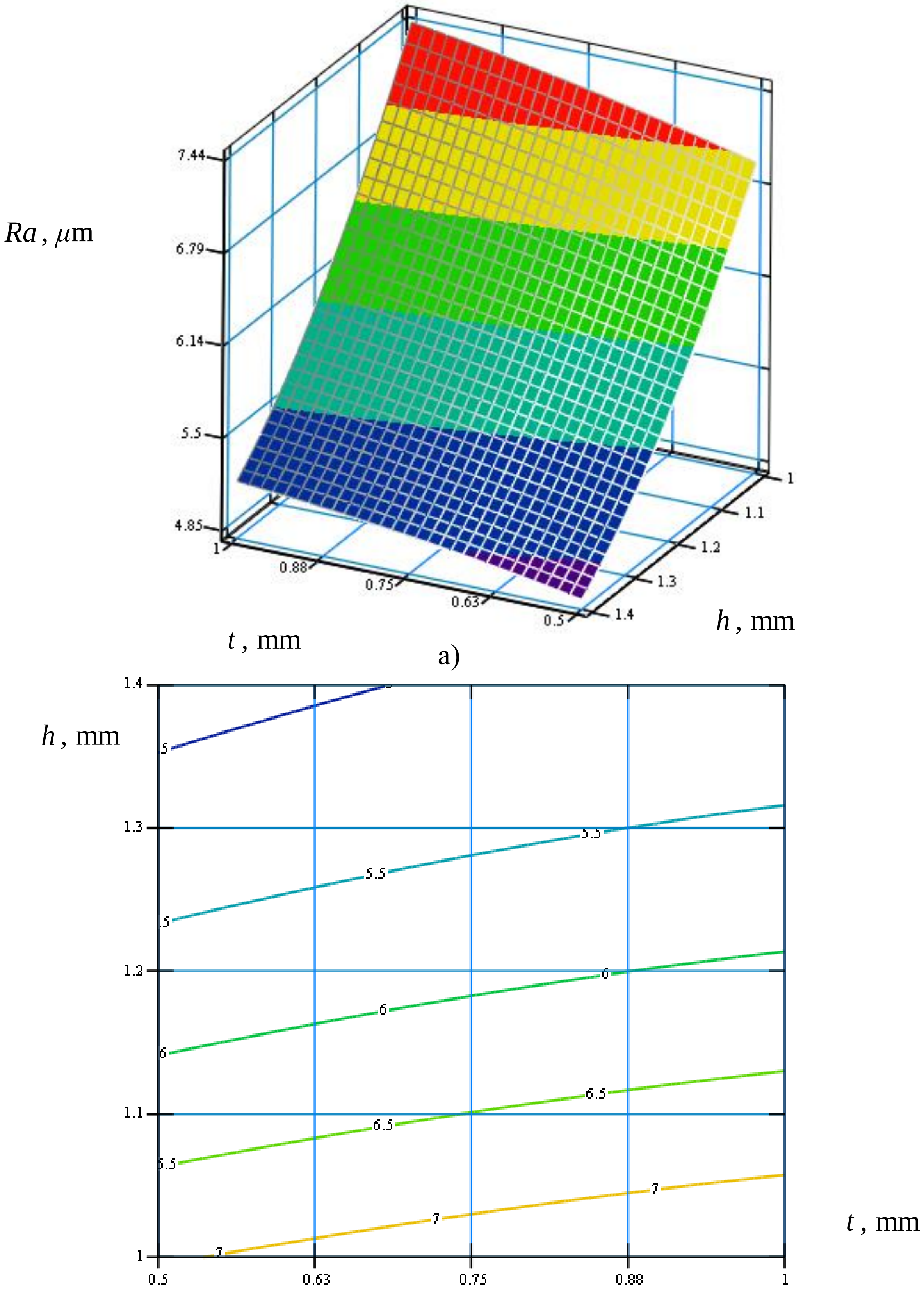
Figure 2.10 – The response surface (a) and two-dimensional cross-section of the response surface (b) dependence of the thin-walled ribbed elements roughness after turning from the cutter feed *S* and the depth of cut *t* (*h*=1.2 mm)



a)

b)

Figure 2.11 – The response surface (a) and two-dimensional cross-section of the response surface (b) dependence of the thin-walled ribbed elements roughness after turning from the cutter feed *S* and the thickness of the thin-walled ribbed elements *h* (t=0.75 mm)



a)

b)

Figure 2.12 – The response surface (a) and two-dimensional cross-section of the response surface (b) dependence of the thin-walled ribbed elements roughness after turning from the depth of cut *t* and the thickness of the thin-walled ribbed elements *h* (*S*=0.15 mm/rev)

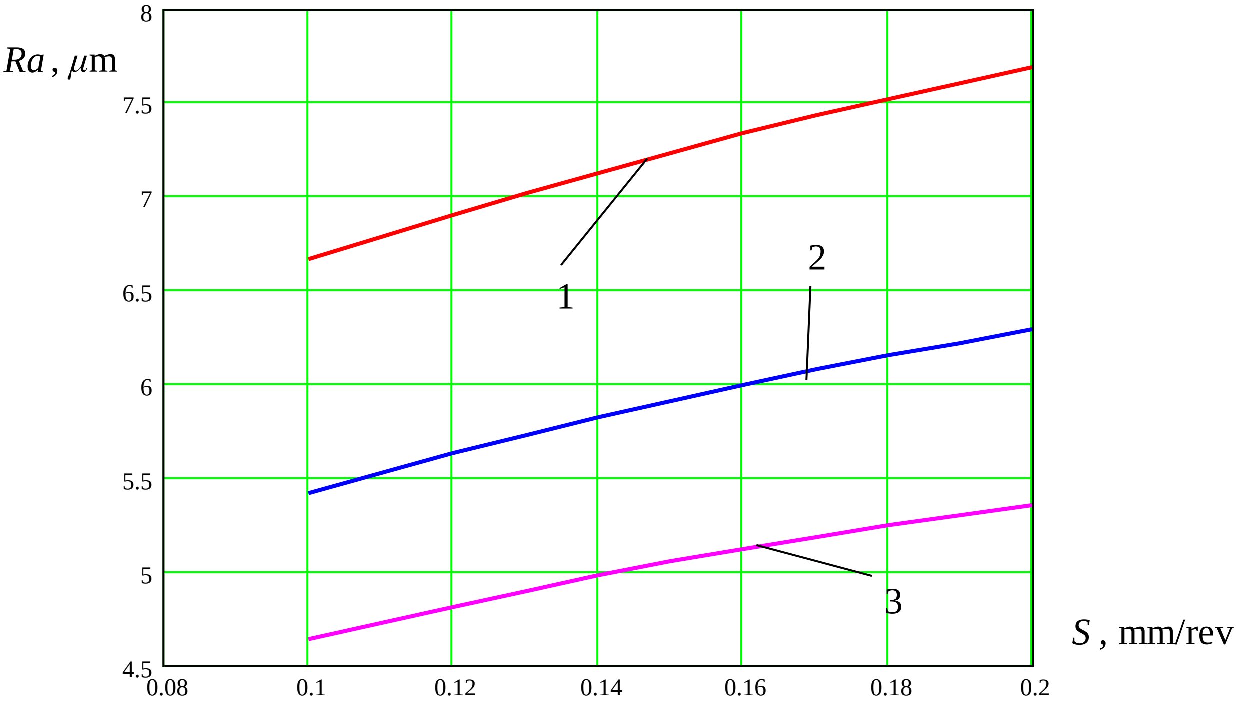


Figure 2.13 – Graphic dependencies of the thin-walled ribbed elements roughness after turning from the cutter feed S, t=0.75 mm: 1) h=1 mm; 2) h=1.2 mm; 3) h=1.4 mm

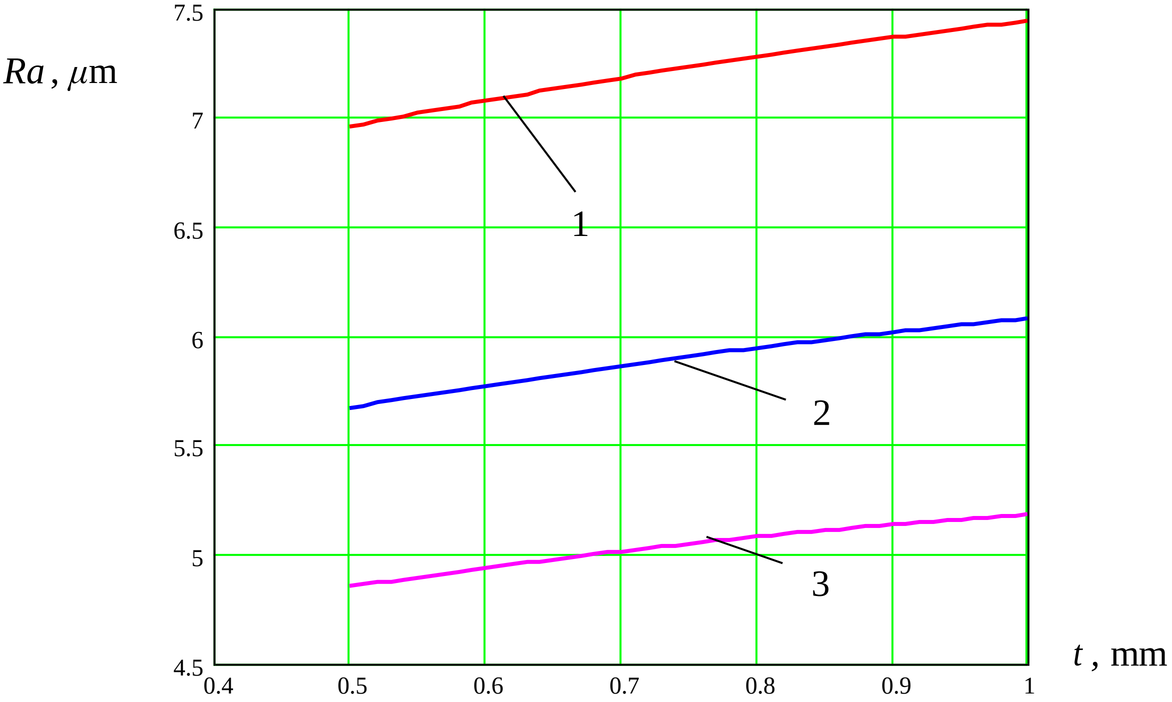


Figure 2.14 – Graphic dependencies of the thin-walled ribbed elements roughness after turning from depth of cut t, S=0.15 mm/rev: 1) h=1 mm; 2) h=1.2 mm; 3) h=1.4 mm

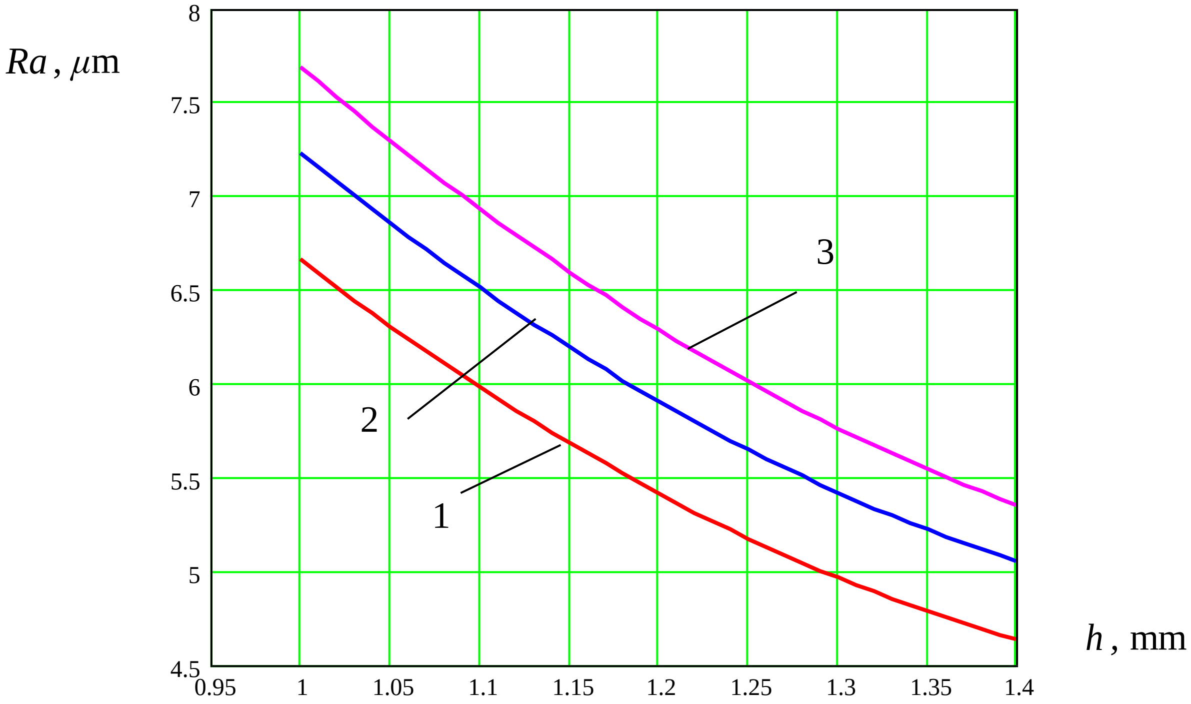


Figure 2.15 – Graphic dependencies of the thin-walled ribbed elements roughness after turning from the thickness of the thin-walled ribbed elements *h*, *t*=0.75 mm: 1) *S*=0.1 mm/rev; 2) *S*=0.15 mm/rev; 3) *S*=0.2 mm/rev

2.3. Conclusions

The dynamics of the cylindrical part with thin-walled ribbed elements turning studied in the part. A system of differential equations describing the oscillations of the elements of the equivalent multimass system is derived. The solution of the system of differential equations is performed using application software that uses a subroutine of the Runge-Kutta numerical method with initial coordinates determined from equations. The solution is presented in the form of numerical data and graphs.

Based on the constructed graphs it is established that the deformations of the thin-walled ribbed element in time have a variable character with a sharp increase at the time of impact with the cutter. After the impact, the oscillations of such element are damped.

The maximum deformation of the thin-walled ribbed element is 0.04 mm. The largest deformation of the cutter is 0.0065 mm. This difference is due to the fact that the stiffness of the cutter is higher than the stiffness of the thin-walled ribbed element.

The results of experimental studies of the thin-walled ribbed elements roughness of the workpiece after turning are presented. It was concluded that the thickness of the thin-walled ribbed elements *h* has the greatest influence on the roughness *Ra* of thin-walled ribbed elements after turning, and the depth of cut *t* has the smallest influence. With increasing cutter feed *S* and depth of cut *t*, the roughness *Ra* of thin-walled ribbed elements after turning increases, and with increasing thickness of the thin-walled ribbed elements *h* - decreases.

The maximum value of the roughness *Ra* of thin-walled ribbed elements after turning is 7.92 µm, and the minimum is 4.76 µm. Increasing the cutter feed *S* from 0.1 mm/rev to 0.2 mm/rev leads to the increase in roughness *Ra* by 16%. Increasing the depth of cut *t* from 0.5 mm to 1 mm increases the roughness *Ra* by 7%, and increasing the thickness of the thin-walled ribbed elements *h* from 0.6 mm to 1 mm decreases the roughness *Ra* by 30%.

3 TECHNOLOGICAL AND DESIGN PART

3.1. The analysis of the part manufacturability

Manufacturability indicators of the body structure 732141.147 are based on the numerical data given in the table 1.1.

Calculation of the coefficient of machining accuracy for the body structure 732141.147:

$$К_{Т.Ч.} = 1 - \frac{1}{Т_{ср}}, \tag{3.1}$$

$$Т_{ср} = \frac{\sum Т_i \cdot n_i}{\sum n_i} = \frac{14 \cdot 18 + 12 \cdot 16 + 9 \cdot 1}{35} = 12.68;$$

$$К_{Т.Ч.} = 1 - \frac{1}{12.68} = 0.92.$$

If $К_{Т.Ч.} = 0.92 > 0.8$, then the body structure 732141.147 is technological.

Calculation of the surface roughness coefficient for the body structure 732141.147:

$$К_{ш} = \frac{1}{Б_{ср}}, \tag{3.2}$$

$$Б_{ср} = \frac{\sum Б_i \cdot n_i}{\sum n_i} = \frac{5 \cdot 1 + 4 \cdot 16 + 3 \cdot 18}{28} = 4.39,$$

$$К_{ш} = \frac{1}{4.39} = 0.23.$$

If $К_{Ш} = 0.23 > 0.16$, then the body structure 732141.147 is technological.

Calculation of the unification of the structural elements for the body structure 732141.147:

$$K_{y.e.} = \frac{N_{y.e}}{N_e} = \frac{32}{35} = 0.91. \quad (3.3)$$

If $K_{y.e.} = 0.91 > 0.6$, then the body structure 732141.147 is technological.

On the basis of the received calculations it is established that the part "Body structure" 732141.147 is technological and there is no need to change its design, technical requirements, material.

3.2. Selection of the workpiece production method

There are various methods of the body structure 732141.147 workpiece manufacturing, among which two methods are considered:

1) casting in the sand molds, formed by the special machine and metal models;

2) die casting in molds using special machines.

Calculations of allowances for the body structure 732141.147 were performed using known methods and tabular data of handbooks (table 3.1).

Formulas for the volume and the mass of the workpieces calculation:

$$Q = q + m_{пр}, \quad (3.4)$$

$q = 0.318$ – the mass of the part, kg;

$$m_{пр} = V_{пр} \cdot \rho. \quad (3.5)$$

Table 3.1 – Allowances of the body structure 732141.147

Machined surface, its dimension, accuracy	Surface roughness, μm	Workpiece tolerance, mm	Total allowance, mm	Workpiece dimension with deviations
1	2	3	4	5
1) casting in the sand molds, formed by the special machine and metal models: the class of accuracy of the sizes and weights – 11-th class; the number of allowances for machining - 3.				
Internal cylindrical surface $\varnothing 173H9(^{+0.1})$	Ra2.5	5.6	8.0 × 2 = 16.0	$\varnothing 165 \pm 2.8$

Continuation of table 3.1

1	2	3	4	5
End face 68h14($_{-0.74}$)	Ra12.5	4.4	5.0	73±2.2
Internal end face 8±0.1	Ra12.5	2.4	3.2	4.8±1.2 on the drawing 9.8±1.2
Internal radial surface R16.4±0.1	Ra12.5	2.8	2.4	R14±1.4
Internal end face 7.1$^{+0.2}$	Ra12.5	2.4	1.6	5.5±1.4 on the drawing 8.5±1.4
2) die casting in molds using special machines: the class of accuracy of the sizes and weights – 7-th class; the number of allowances for machining - 1.				
Internal cylindrical surface ∅173H9($^{+0.1}$)	Ra2.5	1.4	2.4 × 2 = 4.8	∅168.2±0.7
End face 68h14($_{-0.74}$)	Ra12.5	1.1	1.2	69.2±0.55
Internal end face 8±0.1	Ra12.5	0.64	1.0	7±0.32
Internal radial surface R16.4±0.1	Ra12.5	0.8	1.0	R15.4±0.4
Internal end face 7.1$^{+0.2}$	Ra12.5	0.64	1.0 × 2 = 2.0	5.1±0.32

The volume of the cylindrical elements of the part:

$$V_{\text{пр}} = \frac{\pi \cdot D^2 \cdot H}{4}. \qquad (3.6)$$

Determination of the allowances volume:

- casting in the sand molds, formed by the special machine and metal models:

$$V_{\text{пр}1} = \frac{\pi \cdot (179^2 - 165^2) \cdot 5}{4} = 18902.8 \text{ mm}^3;$$

$$V_{\text{пр}2} = \frac{\pi \cdot (165^2 - 128^2) \cdot 3.2}{4} = 27232.6 \text{ mm}^3;$$

$$V_{\text{пр}3} = \frac{\pi \cdot (32.8^2 - 28^2) \cdot 7.1}{8} = 813.3 \text{ mm}^3;$$

$$V_{\text{пр}} = \sum V_{\text{пр}_i};$$

$$V_{пр} = 18902.8 + 27232.6 + 813.3 = 46948.7\,mm^3 = 46{,}95\ sm^3.$$

– die casting in molds using special machines:

$$V_{пр1} = \frac{\pi \cdot (179^2 - 168.2^2) \cdot 1.2}{4} = 3532.3\ mm^3;$$
$$V_{пр2} = \frac{\pi \cdot (168.2^2 - 128^2) \cdot 1.0}{4} = 9347.2\ mm^3;$$
$$V_{пр3} = \frac{\pi \cdot (32.8^2 - 30.8^2) \cdot 7.1}{8} = 354.5\ mm^3;$$

$$V_{пр} = \sum V_{пр_i};$$

$$V_{пр} = 3532.3 + 9347.2 + 354.5 = 13234\,mm^3 = 13.23\ sm^3.$$

Total mass of allowances:

– casting in the sand molds, formed by the special machine and metal models:

$$m_{пр1} = 46.95 \cdot 2.6 = 122.07\,g = 0.122\,kg.$$

– die casting in molds using special machines:

$$m_{пр2} = 13.23 \cdot 2.6 = 34.4\,g = 0.034\ kg.$$

The mass of the workpiece is determined based on preliminary calculations:

– casting in the sand molds, formed by the special machine and metal models:

$$Q_1 = 0.43 + 0.38 = 0.81\,kg.$$

– die casting in molds using special machines:

$$Q_2 = 0.43 + 0.097 \approx 0.53\ kg.$$

The materials utilization rates

$$К_{в.м.} = \frac{q}{Q}, \qquad (3.7)$$

– casting in the sand molds, formed by the special machine and metal models:

$$К_{в.м.1} = \frac{0.318}{0.44} = 0.72.$$

– die casting in molds using special machines:

$$К_{в.м.2} = \frac{0.318}{0.35} = 0.9.$$

Die casting in molds using special machines is used for the workpiece production comparing the materials utilization rates.

3.4. Design of the technological route

The comparison of the two routes of the body structure 732141.147 machining with the choice of the optimal is given in the table 3.3.

Table 3.3 – The comparison of the two routes of the body structure 732141.147 machining

№ surface	Type of surface	Initial parameters of the part		Variants of methods and routes of surfaces machining	
		Surface finish	Roughness, μm	1	2
1	2	3	4	5	6
1	End face 68	Not machined	Rz50	–	–
2, 8	Trough hole $\varnothing 3.3H12(^{+0.12})$ for thread M4-7H, L=7	12	Ra6.3	Drilling on the jig	1) Centering 2) Drilling
5, 17	Trough hole $\varnothing 3.3H12(^{+0.12})$ під різь M4-7H, L=5.5	12	Ra6.3	Drilling on the jig	1) Centering 2) Drilling
11, 14	Trough hole $\varnothing 3.3H12(^{+0.12})$ for thread M4-7H, L=6.5	12	Ra6.3	Drilling on the jig	1) Centering 2) Drilling
29, 32	Blind hole $\varnothing 3.3H12(^{+0.12})$ for thread M4-7H, L=8	12	Ra6.3	Drilling on the jig	1) Centering 2) Drilling
3, 6, 9, 12, 15, 18, 30, 33	Internal chamfer 0.5×45°	14	Ra12.5	Countersinking	Machining by combined cutting tool during drilling or centering
4, 9	Internal thread surface M4-7H, L=7	12	Ra6.3	Threading by tap	–
7, 19	Internal thread surface M4-7H, L=5.5	12	Ra6.3	Threading by tap	–
13, 16	Internal thread surface M4-7H, L=6.5	12	Ra6.3	Threading by tap	–
31, 34	Internal thread surface M4-7H, L=6	12	Ra6.3	Threading by tap	–
20, 21	Hole $\varnothing 12H14(^{+0.43})$, L=2.5	14	Ra12.5	Drilling on the jig	1) Centering 2) Drilling

Continuation of table 3.3

1	2	3	4	5	6
22-24	Internal radial surface R16.4±0.1; 92±0.1; 7.1$^{+0.2}$; 8.3±0.1	14	Ra12.5	Milling by T-slot cutter	–
25, 26, 27	Hole ∅6H14($^{+0.3}$), L=11	14	Ra12.5	Drilling on the jig	1) Centering 2) Drilling
35	End face 68h14($_{-0.74}$)	14	Ra12.5	Semifinish form turning with transverse feed	–
36	Internal end face 8±0.1	14	Ra12.5	Semifinish form turning with transverse feed	–
37	Internal cylindrical surface ∅173H9($^{+0.1}$)	9	Ra2.5	1) Semifinish boring 2) Finish boring	–

The optimal route of the body structure 732141.147 machining.

005 Semiautomatic turning

1. Finish form turning of the end face 35 from the transverse sliding carriage to the dimension $68_{-0.74}$.

2. Semifinish boring of the hole 37 with end face 36 cutting from the longitudinal sliding carriage to the dimensions ∅172.51 $^{+0.25}$; 8±0.1.

3. Finish boring of the hole 37 from the longitudinal sliding carriage to the dimension ∅173.0 $^{+0.1}$.

Control dimensions: $68_{-0.74}$, 8±0.1, ∅173.0 $^{+0.1}$.

010. Vertical milling

1. Milling of the recess 22 to the dimension R16.4±0.1.

2. Rotation of the part by 120°.

3. Milling of the recess 23 to the dimension R16.4±0.1.

4. Rotation of the part by 120°.

5. Milling of the recess 24 to the dimension R16.4±0.1.

Control dimensions: R16.4±0.1, 120°.

015. Multihead machining

Position II. Drilling of four holes 2, 8, 11, 14 with forming of chamfers 5, 9, 12, 15 simultaneously from force head IIa to the dimensions $\varnothing 3.3^{+0.12}$; 0.5×45°; 52±0.2; 34±0.2; l=6.5; l=7.

Position III. Drilling of three holes 5, 29, 32 with forming of chamfers 6, 30, 33, to the dimensions $\varnothing 3.3^{+0.12}$; 0.5×45°; 112±0.2; l=8, drilling of three holes 25, 26, 27 simultaneously from force head IIIa to the dimensions $\varnothing 6^{+0.3}$; ∅186±0.1; l=11.

Position IV. Drilling of two holes 20, 21 simultaneously from force head IVa, to the dimensions $\varnothing 12^{+0.43}$; 36±0.2; l=2.5.

Position V. Drilling of the hole 17 with forming of chamfer 18 from force head Va, to the dimensions $\varnothing 3.3^{+0.12}$; 0.5×45°; ∅36±0.2; l=5.5.

Position VI. Tapping threads 5, 10, 13, 16 in four holes simultaneously from force head VIa, to the dimensions M4-7H; l=6.5; l=7.

Position VII. Tapping threads 7, 31, 34 in three holes simultaneously from force head VIIa, to the dimensions M4-7H; 112±0.2; l=6.

Position VIII. Tapping thread 19 in the hole from force head VIIIa, to the dimensions M4-7H; ∅36±0.2; l=5.5.

Control dimensions: $\varnothing 6^{+0.3}$; ∅186±0.1; 0.5×45°; $\varnothing 12^{+0.43}$; 36±0.2; 52±0.2; 34±0.2; M4-7H; l=6. Control 30%

020 Inspection.

3.5. Determination of allowances for machining

Calculations of allowances for the body structure 732141.147 were performed using known methods and tabular data of handbooks (table 3.4).

Table 3.4 –Calculated allowances

Technological operations and operation elements	Surface finish	Surfaces roughness, μm	Tolerance, mm	Allowance, mm	Operational dimensions with deviations
1	2	3	4	5	6
End face 68h14($_{-0.74}$)					
Semifinish turning	14	Ra12.5	0.74	1.2	$68_{-0.74}$
Workpiece	7-th class	R_z50	1.1	–	69.2±0.55
Internal end face 8±0.1					
Semifinish turning	14	Ra12.5	0.2	1.0	8±0.1
Workpiece	7-th class	R_z50	0.64		7±0.32
Internal radial surface R16.4±0.1					
Milling by T-slot cutter	14	Ra12.5	0.2	1.0	R16.4±0.1
Workpiece	7-th class	R_z50	0.8	–	R15.4±0.4
Internal end face $7.1^{+0.2}$					
Milling by T-slot cutter	14	Ra12.5	0.2	1.0 × 2 = 2.0	$7.1^{+0.2}$
Workpiece	7-th class	R_z50	0.64	–	5.1±0.32

3.6. Determination of cutting conditions

Cutting conditions for specific operations, cutting and auxiliary tools, equipment models are presented in the appendices.

Calculations of cutting conditions for machining operations of the body structure 732141.147 were performed using known techniques and tabular data of handbooks (table 3.5).

Table 3.5 – Cutting conditions for the body structure 732141.147 machining operations

Number, name of operation and operation element	t, mm	L, mm	i	T_m, min	S, mm/ rew	n, rew/ min	V, m/ min	S_m, mm/ min	T_o, min	N, kW
1	2	3	4	5	6	7	8	9	10	11
005 Semiautomatic turning										
Operation element 2 Finish form turning of the end face 35 from the transverse sliding carriage to the dimension $68_{-0.74}$.	1.2	27.2	1	55	0.081	854	477.7	68	0.4	1.0
Operation element 3 Semifinish boring of the hole 37 with end face 36 cutting from the longitudinal sliding carriage to the dimensions $\varnothing 172.51^{+0.25}$; 8±0.1.	2.355 1.0	34	1	55	0.1	854	464	85	0.4	1.2
Operation element 4 Finish boring of the hole 37 from the longitudinal sliding carriage to the dimension $\varnothing 173.0^{+0.1}$.	0.245	17	1	55	0.05	854	464	42.7	0.4	0.06
010 Vertical milling										
Operation element 1 Milling of the recess 22 to the dimension R16.4±0.1.	1.0	34	1	65	0.1 mm/ tooth	2240	98.5	227	0.14	1.2
Rotation of the part by 120°.										
Operation element 2 Milling of the recess 23 to the dimension R16.4±0.1.	1.0	34	1	65	0.1 mm/ tooth	2245	98.7	227	0.14	1.2
Rotation of the part by 120°.										
Operation element 3 Milling of the recess 24 to the dimension R16.4±0.1.	1.0	34	1	65	0.1 mm/ tooth	2245	98.7	227	0.14	1.2

Continuation of table 3.5

1	2	3	4	5	6	7	8	9	10	11
015 Multihead machining										
Position 2 Drilling of four holes 2, 8, 11, 14 with forming of chamfers 5, 9, 12, 15 simultaneously from force head IIa to the dimensions ∅$3.3^{+0.12}$; 0.5×45°; 52±0.2; 34±0.2; l=6.5; l=7.	1.65	13	1	85	0.08	2005	20.8	162	0.07	0.32
Position 3 Drilling of three holes 5, 29, 32 with forming of chamfers 6, 30, 33, to the dimensions ∅$3.3^{+0.12}$; 0.5×45°; 112±0.2; l=8, drilling of three holes 25, 26, 27 simultaneously from force head IIIa to the dimensions ∅$6^{+0.3}$; ∅186±0.1; l=11.	1.65 3.0	18	1	91.8	0.12	1355	25.7	162	0.10	1.27
Position 4 Drilling of two holes 20, 21 simultaneously from force head IVa, to the dimensions ∅$12^{+0.43}$; 36±0.2; l=2.5.	6.0	13	1	35	0.28	575	21.7	162	0.07	2.17
Position 5 Drilling of the hole 17 with forming of chamfer 18 from force head Va, to the dimensions ∅$3.3^{+0.12}$; 0.5×45°; ∅36±0.2; l=5.5.	1.65	11.5	1	75	0.08	2005	10.4	162	0.07	0.08

Continuation of table 3.5

1	2	3	4	5	6	7	8	9	10	11
Position 6 Tapping threads 5, 10, 13, 16 in four holes simultaneously from force head VIa, to the dimensions M4-7H; l=6.5; l=7.	0.38	14.6	1	97	0.7	235	3	165	0.17	0.7
Position 7 Tapping threads 7, 31, 34 in three holes simultaneously from force head VIIa, to the dimensions M4-7H; 112±0.2; l=6.	0.38	13.6	1	82.5	0.7	235	3	165	0.15	0.06
Position 8 Tapping thread 19 in the hole from force head VIIIa, to the dimensions M4-7H; ∅36±0.2; l=5.5.	0.38	11.1	1	77	0.7	235	3	165	0.15	0.02

Calculations of technical norms of time for machining operations of the body structure 732141.147 were performed using known techniques and tabular data of handbooks (table 3.6).

Table 2.10 – Technical norms of time for the body structure 732141.147 machining

Number, name of operation	$T_{\text{о}}$, min	Additional time, $T_{\text{д}}$ min			Time of rapid movements, min	Machine cycle time, $T_{\text{ц}}$, min	Service time, $T_{\text{об}}$, min			$T_{\text{шт}}$, min.	$T_{\text{п.з.}}$ min	n, pcs	$T_{\text{шт.к.}}$, min
		$T_{\text{у.}}$	$T_{\text{пер.}}$	$T_{\text{вим.}}$			$T_{\text{тех.об.}}$	$T_{\text{орг.об.}}$	$T_{\text{відп.}}$				
005 Semiautomatic turning	0.4	–	–	–	–	–	–	–	–	–	–	2530	0.84
010 Vertical milling	0.45	–	–	–	–	–	–	–	–	–	–		0.7
015 Multihead machining	0.18	0.12	0.01	0.91	0.08	0.26	0.0036	0.0063	0.016	1.2	82.5		1.23

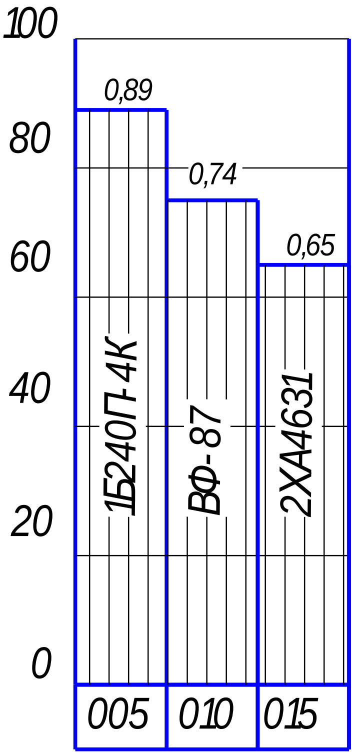


Figure 3.3 - Schedule of equipment loading

3.7. Calculation of the fixture drive

The special fixture is presented in the graphic part with the calculation scheme on the Fig. 3.4. for the body structure 732141.147 machining on the 015 Multihead machining operation. The required forces for clamping workpiece in this operation are determined.

Equilibrium condition under the action of cutting torques and torques of friction forces that occur when clamping the workpiece [23]:

$$KM_{\text{різ}} = \sum M_{\text{тр}}, \tag{3.8}$$

where K - safety coefficient.

Torques of friction forces that occur when clamping the workpiece [23]:

$$\sum M_{\text{тр}} = P_{\text{зат}} \cdot R \cdot f_1 + \frac{2P_{\text{зат}} f_2 \cdot \left(R_2^3 - R_1^3\right)}{3\left(R_2^2 - R_1^2\right)}, \tag{3.9}$$

where f_1=0.3; f_2 =0.3; R_1=86.5 mm; R_2=89.5mm; R=30mm.

From equations (3.8) - (3.9) the clamping force for the workpiece is obtained:

$$P_{зат} = \frac{KM_{різ}}{f_1 \cdot R + 2f_2 \cdot \frac{R_2^3 - R_1^3}{3(R_2^3 - R_1^3)}} + P_0. \tag{3.10}$$

Cutting torque:

$$M_{різ1,2} = 10 \cdot C_м \cdot D^q \cdot S^y \cdot K_p, \tag{3.11}$$

where $C_M = 0.005$; $q = 2.0$; $y = 0.8$.

$D = 3.3$ mm

$S = 0.12$ mm/rev.

$$K_p = K_{мр},\ K_{мр} = \left(\frac{\sigma_в}{750}\right)^n = \left(\frac{980}{750}\right)^{0.75} = 1.22.$$

Therefore, $M_{різ1} = 10 \cdot 0.005 \cdot 6^2 \cdot 0.12^{0,8} \cdot 1.22 = 0.4\ N \cdot m$;

$M_{різ2} = 10 \cdot 0.005 \cdot 3.3^2 \cdot 0.12^{0,8} \cdot 1.22 = 0.12\ N \cdot m.$

Total cutting torque:

$$M_{різ} = 3M_{різ1} + 3M_{різ2};$$

$$M_{різ} = 3 \cdot 0.4 + 3 \cdot 0.12 = 1.56 N \cdot m.$$

Safety coefficient K [20]:

$$K = 1.5 \cdot 1.2 \cdot 1.15 \cdot 1.2 \cdot 1.05 \cdot 1.0 \cdot 1.0 = 2.6.$$

From equation (3.4) the clamping force for the workpiece is obtained:

$$P_{зат} = \frac{2.6 \cdot 1.56}{0.3 \cdot 0.03 + 2 \cdot 0.3 \cdot \frac{0.0895^3 - 0.0865^3}{3 \cdot \left(0.0895^2 - 0.0865^2\right)}} + 2400 = 2528 N.$$

Verifying calculation of clamping force:

$$P_{\text{зат}} \leq F_{\text{шт.тяг.}} \cdot i, \tag{3.12}$$

where $F_{\text{шт.тяг.}}$ – the force on the piston rod of the pneumatic cylinder.

The force on the piston rod of the pneumatic cylinder [14]:

$$F_{\text{шт.тяг.}} = 0.785 \cdot (D_{\text{ц}}^2 - d_{\text{шт}}^2) \cdot p \cdot \eta, \tag{3.13}$$

$$F_{\text{шт.тяг.}} = 0.785 \cdot (0.1^2 - 0.032^2) \cdot 0.4 \cdot 10^6 \cdot 0.9 = 2536\,\text{N}.$$

Push force of the pneumatic cylinder taking into account increasing by means of the wedge mechanism [23]:

$$W = \frac{F_{\text{шт.тяг.}}}{\left(\text{tg}\left(\beta + \text{arctg}\left(\varphi \cdot \frac{d}{D}\right)\right) + \text{tg}\varphi_1\right)}, \tag{3.14}$$

where $\beta=10°$; $d = 12$ mm; $D = 24$ mm.

Then

$$W = \frac{2536}{\left(\text{tg}\left(10 + \text{arctg}\left(6 \cdot \frac{12}{24}\right)\right) + \text{tg}6\right)} = 4474\,\text{N}.$$

The condition of the workpiece clamping is considered

$$W > P_{\text{зат}}.$$

In our case $W = 4474\,\text{N} > P_{\text{зат}} = 2528$ N.

Conclusion: the condition of the workpiece of the body structure 732141.147 clamping on the 015 Multihead machining operation is provided.

4 SAFETY MEASURES IN EMERGENCIES

4.1. Machinery guarding and protection against mechanical hazards

Machinery and its components and fittings should be stable enough to avoid overturning, falling or uncontrolled movements during use, transportation, assembly and dismantling. If the shape of the machinery itself or its intended installation does not offer sufficient stability, appropriate means of anchorage should be incorporated and indicated in the instructions. All information in this chapter is taken from [34].

The various parts of machinery and their linkages should be able to withstand the stresses to which they are subject when used. The durability of the materials used should be adequate for the nature of the working environment foreseen by the manufacturer, in particular as regards the phenomena of fatigue, ageing, corrosion and abrasion, and the maintenance schedule of the owner.

The instructions should indicate the type and frequency of inspections and maintenance required for safety reasons. They should, where appropriate, indicate the parts subject to wear and the criteria for replacement.

Where a risk of rupture or disintegration remains despite the measures taken, the parts concerned should be mounted, positioned and guarded in such a way that any fragments will be contained, preventing hazardous situations.

Rigid or flexible pipes carrying fluids, particularly those under high pressure, should be able to withstand foreseeable internal and external stresses and should be firmly attached and protected to ensure that no risk is posed by a rupture.

Where the material to be processed is fed to the tool automatically, the following conditions should be met so as to prevent risks to persons:

(a) when the workpiece comes into contact with the tool, the latter should have attained its normal working condition; and

(b) when the tool starts and stops (intentionally or accidentally), the feed movement and the tool movement should be coordinated.

Measures should be taken to prevent risks arising from falling or ejected objects.

In so far as their purpose allows, parts that are accessible during use and maintenance of the machinery should have no sharp edges, sharp angles or rough surfaces likely to cause injury.

Where the machinery is intended to carry out several different operations with manual removal of the piece between each operation (combined machinery), it should be designed and constructed in such a way as to enable each element to be used separately, without the other elements constituting a risk to exposed persons.

Where the machinery performs operations under different conditions of use, it should be designed and constructed in such a way that selection and adjustment of these conditions can be carried out safely and reliably.

Prevention of hazards due to moving parts of machinery should take into account:

(a) the movement of machinery parts consisting basically of rotary, sliding or reciprocating motion, or a combination of these, such as the movements of spindles, chucks, fan blades, counter-rotating gear wheels or rollers, and stroking blades; and

(b) the movement of machinery parts which may have the potential to cause injury, for example by entanglement, friction or abrasion, cutting, shearing, stabbing or puncture, impact, crushing, or drawing a person into a position where injury can occur.

Moving parts of machinery should be designed and constructed in such a way as to prevent risks of contact which could lead to accidents and should, where risks persist, be fitted with guards or protective devices.

All necessary steps should be taken to prevent accidental blockage of moving parts involved in the work. If a blockage remains possible despite the precautions taken, the necessary specific protective devices and tools should be provided to enable the equipment to be unblocked safely. The instructions and, where possible, a sign on the machinery should identify these specific protective devices and how they are to be used.

Guards or protective devices designed to protect against risks arising from moving parts should be selected on the basis of the type of risk.

Guards designed to protect persons against the hazards generated by moving transmission parts should be either:

(a) fixed guards; or

(b) interlocking movable guards.

Interlocking movable guards should be used where frequent access is envisaged. When a process requires access to a danger zone and a fixed guard is impracticable, an interlocking guard should be considered.

Guards or protective devices designed to protect persons against the hazards generated by moving parts involved in the process should be:

(a) fixed guards;

(b) interlocking movable guards;

(c) protective devices; or

(d) a combination of the above.

However, when certain moving parts directly involved in the process cannot be made completely inaccessible during operation because of the need for operator intervention, such parts should be fitted with:

(a) fixed guards or interlocking movable guards preventing access to parts to which access is not necessary for the purpose of the work which has to be performed; and

(b) adjustable guards restricting access to those sections of the moving parts to which access is necessary.

When a part of the machinery has been stopped, any drifting away from the stopping position for whatever reason other than action on the control devices should be prevented or should not present a hazard.

Guards and protective devices should protect against danger, including risks from moving parts. They should:

(a) be of robust construction;

(b) be securely held in place;

(c) not give rise to any additional hazard;

(d) not be easy to bypass or render non-operational, or be easily defeated;

(e) be located at an adequate distance from the danger zone;

(f) cause minimum obstruction of the view of the production process; and

(g) enable essential work to be carried out on the installation and replacement of tools and for maintenance purposes by restricting access exclusively to the area where the work has to be done, if possible without the guard having to be removed or the protective device having to be disabled.

In addition, guards should protect against the ejection or falling of materials or objects and against emissions generated by the machinery.

Fixed guards should be used whenever practicable. They should be designed so as to prevent access to the dangerous parts of the machinery. Fixed guards should be fixed by systems that can be opened or removed only with tools. Their fixing (attachment) systems should remain attached to the guards or to the machinery when the guards are removed. Where possible, guards should be incapable of remaining in place without their fixings (attachments).

Interlocking movable guards should, as far as possible, remain attached to the machinery when open. Interlocking movable guards should be associated with an interlocking device which:

(a) prevents the start of hazardous machinery functions until the guards are closed; and

(b) gives a stop command whenever the guards are opened.

Where it is possible for an operator to reach the danger zone before the risk due to the hazardous machinery functions has ceased, movable guards should be associated with a guard-locking device in addition to an interlocking device which:

(a) prevents the start of hazardous machinery functions until the guard is closed and locked; and

(b) keeps the guard closed and locked until the risk of injury from the hazardous machinery functions has ceased.

Interlocking movable guards should be designed in such a way that the absence or failure of one of their components prevents starting, or stops the hazardous machinery functions. Adjustable guards restricting access to those areas of the moving parts strictly necessary for the work should be:

(a) adjustable manually or automatically, depending on the type of work involved; and

(b) readily adjustable without the use of tools.

Protective devices should be designed and incorporated into the control system in such a way that:

(a) moving parts cannot start up while they are within the operator’s reach;

(b) persons cannot reach moving parts while those parts are moving; and

(c) the absence or failure of one of their components prevents starting or stops the moving parts.

Protective devices should be adjustable only by means of an intentional action.

4.2. Technical information to offset hazards due to lifting operations

The lifting device should be of sufficient capacity and suitable for the purpose of lifting. A lifting device which is either mobile or capable of being dismantled and which is designed for lifting loads should be used in such a way as to ensure its stability during use under all foreseeable conditions. The nature of the ground should also be taken into account. All information in this chapter is taken from [34].

The maximum permissible load of the lifting device should not be exceeded. When two or more items of machinery used for lifting nonguided loads are installed or erected on a site in such a way that their working radii overlap, appropriate measures should be taken to prevent collisions between the loads and the machinery parts themselves.

When using mobile machinery for lifting non-guided loads, measures should be taken to prevent the equipment from tilting, overturning, moving or slipping. Checks should be made to ensure that these measures are implemented properly. If the operators of machinery designed for lifting nonguided loads cannot observe the full path of the load either directly or by means of auxiliary equipment, a competent person should be in communication with the operators to guide them. Organizational measures should be taken to prevent collisions involving the load which could endanger workers.

Work should be organized in such a way that a worker can safely attach or detach a load by hand, in particular by ensuring that workers retain direct or indirect control of the machinery.

In particular, if a load has to be lifted by two or more pieces of machinery for lifting non-guided loads simultaneously, a procedure should be established and applied to ensure good coordination on the part of the operators. Measures should be taken to ensure that workers are not present underneath suspended loads, unless their presence there is required for the effective performance of the work.

If machinery designed for lifting non-guided loads cannot maintain its hold on the load in the event of a complete or partial power failure, appropriate measures should be taken to avoid exposing workers to any resultant risks. Suspended loads should not be left without surveillance unless access to the danger zone is prevented and the load has been safely suspended and is safely held.

Outdoor machinery designed for lifting non-guided loads should not continue when meteorological conditions deteriorate to the point of jeopardizing the safe use of the equipment and exposing workers to risks. Adequate protection measures, in particular to prevent the machinery from turning over, should be taken to prevent any risks to workers.

Loads should not normally be moved above unprotected workplaces that are usually occupied by workers. Where that is absolutely unavoidable because the work cannot be carried out properly in any other way, appropriate procedures should be established and applied.

Machinery should be designed and constructed in such a way that its stability is maintained both in and out of service, including at all stages of transportation, assembly and dismantling, during foreseeable component failures, and during any tests carried out in accordance with the instruction handbook (operator’s manual).

Machinery should be provided with devices which act on the guide rails or tracks to prevent derailment. If, despite such devices, there remains a risk of derailment or of failure of a rail or of a running component, devices should be provided to prevent the equipment, component or load from falling or the machinery from overturning.

Machinery, lifting accessories and their components should be capable of withstanding the stresses to which they are subjected whether in use or not in use, under the installation and operating conditions provided for and in all relevant configurations, with due regard to any potential effects of conditions of use and forces exerted by persons. This requirement should also be satisfied during transport, assembly and dismantling.

Machinery and lifting accessories should be designed and constructed in such a way as to prevent failure from fatigue and wear, taking due account of their intended use.

4.3. General statements on the working environment in workshop

Measures should be taken to ensure that materials used to construct machinery, and products used or created during its use, do not endanger safety or health of people. In particular, where fluids are used, the machinery should be designed and constructed so as to prevent risks from filling, use, recovery and draining. All information in this chapter is taken from [34].

Adequate and suitable lighting should be provided for the operation of machinery so that machinery movements, controls and displays can easily be seen. Machinery should be supplied with integral lighting suitable for the operations concerned where the absence of such lighting would be likely to cause a risk despite ambient lighting of normal intensity. Such lighting should not cause dangerous stroboscopic effects, dazzle or harmful shadow. Localized lighting should be provided around the work area when the machinery or guards render normal lighting inadequate for safe operation. Localized lighting should also be provided in regular maintenance areas that are poorly lit, for example inside certain electrical compartments where electrical isolation is necessary for access. Artificial lighting should not produce glare or disturbing shadows. Internal parts requiring inspection and adjustment, as well as the maintenance areas, should be provided with appropriate lighting.

Machinery and each component part thereof should:

(a) be capable of being handled and transported safely; and

(b) be designed and packaged so that it can be stored safely and protected from damage.

Machinery should be designed to ensure that during transportation of the machinery and its component parts there should be no possibility of sudden movements or hazards due to instability as long as the machinery and its component parts are handled in accordance with the relevant instructions. Where the weight, size or shape of machinery or its various component parts prevent them from being moved by hand, the machinery or each component part should:

(a) be fitted with attachments for lifting gear; or

(b) be designed so that it can be fitted with such attachments; or

(c) be shaped in such a way that standard lifting gear can easily be attached.

Where machinery, or any of its component parts, is to be moved by hand, it should be either:

(a) easily movable; or

(b) equipped for picking up and moving safely.

Special arrangements should be made for the handling of tools and machinery parts such as sharp edges which, even if lightweight, may be hazardous.

CONCLUSIONS

In the master’s qualifying paper the dynamics of the cylindrical part with thin-walled ribbed elements turning is studied. A system of differential equations describing the oscillations of the elements of the equivalent multimass system is derived. The solution of the system of differential equations is performed using application software that uses a subroutine of the Runge-Kutta numerical method with initial coordinates determined from equations. The solution is presented in the form of numerical data and graphs.

Based on the constructed graphs it is established that the deformations of the thin-walled ribbed element in time have a variable character with a sharp increase at the time of impact with the cutter. After the impact, the oscillations of such element are damped.

The maximum deformation of the thin-walled ribbed element is 0.04 mm. The largest deformation of the cutter is 0.0065 mm. This difference is due to the fact that the stiffness of the cutter is higher than the stiffness of the thin-walled ribbed element.

The results of experimental studies of the thin-walled ribbed elements roughness of the workpiece after turning are presented. It was concluded that the thickness of the thin-walled ribbed elements *h* has the greatest influence on the roughness *Ra* of thin-walled ribbed elements after turning, and the depth of cut *t* has the smallest influence. With increasing cutter feed *S* and depth of cut *t*, the roughness *Ra* of thin-walled ribbed elements after turning increases, and with increasing thickness of the thin-walled ribbed elements *h* - decreases.

The maximum value of the roughness *Ra* of thin-walled ribbed elements after turning is 7.92 μm, and the minimum is 4.76 μm. Increasing the cutter feed *S* from 0.1 mm/rev to 0.2 mm/rev leads to the increase in roughness *Ra* by 16%. Increasing the depth of cut *t* from 0.5 mm to 1 mm increases the roughness *Ra* by 7%, and increasing the thickness of the thin-walled ribbed elements *h* from 0.6 mm to 1 mm decreases the roughness *Ra* by 30%.

The technological process of the body structure 732141.147 manufacturing is improved. The workpiece is defined, locating schemes are developed, cutting tools, equipment, cutting conditions are selected and fixtures are designed.

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