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DEVELOPING A ROTARY MECHANISM OF THE PRODUCT FOR THE WOODWORKING MACHINING CENTERS CNC WITH THE OPTIMIZATION OF ITS ELASTIC SYSTEM PARAMETERS

Master's Program Automation of design and engineering

The abstract of the Master's Thesis

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The thesis work is done at the Federal State Autonomous Educational Institution of Higher Professional Education «Siberian Federal University»

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GENERAL DESCRIPTION OF THE THESIS WORK.

Significance of the work. The theme of the research is associated with the work of creating pilotless aircrafts at Siberian Federal University (Figure 1). Aerial photography based on using pilotless aircrafts allows us to solve many problems of municipal, construction, industrial and forestry sectors of the economy.

For milling processing of samples of pilotless aircrafts a woodworking computer numerical control (CNC) machine was created. Three machine processing parts coordinates (X, Y, Z) were implemented by the control program. The machine is considered to be a frame structure (Figure 1). Working dimensions of the CNC machine are 2500*1300*850 mm. Processing accuracy is 0.05 mm. Operating device is a motor spindle mounted on the console slider (axis Z), which is moved by a ball screw along the slide way bearing (axis X) and against (axis Y) base of the machine.

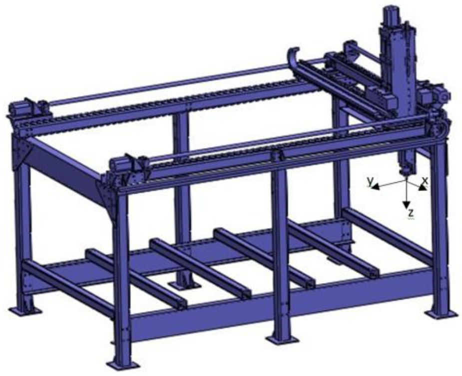

Figure 1 – A woodworking CNC machining center

To increase aerodynamic efficiency and other flight characteristics of pilotless aircrafts it is necessary to complicate geometry of the elements of pilotless aircrafts, and, consequently, to complicate equipment with a larger number of processing axes. To do this, we upgrade the machine by equipping it with a rotary mechanism of a product.

The general view of one of such samples of a pilotless aircraft fuselage is shown in Figure 2. The dimensions of the processing sample are 1790*613*270 mm. The result product accuracy is 0.3-0.4 mm.

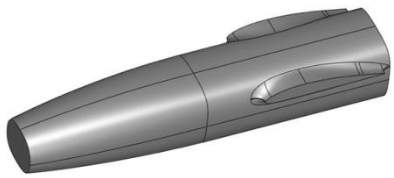

Figure 2 – A work piece of a pilotless aircraft fuselage

To increase the accuracy and productivity of processing samples, it was decided to create an automated rotary mechanism of work piece, mounted on the machine table. The current work deals with the issues of design and study of the product rotary mechanism.

The object of this work is designing a product of a rotary mechanism.

The objective is to design a product rotary mechanism and optimization parameters of its elastic system at the design stage, providing required accuracy of processing products.

To achieve a determined objective it is significant to solve the following **tasks:**

1. To detect workflow characteristics of wooden products cutting by end mill in pilotless aircrafts, the requirements for the kinematic characteristics, structure rigidity and processing accuracy.

2. To develop a mechanism structure of the rotary work piece driven by a step motor.

3. To develop a dynamic model of the machine and the rotary mechanism, to determine its elastic- inertial parameters using a PC "ANSYS" and analytically.

4. To calculate the Eigen values of the dynamic system of the four-coordinate machine and amplitude of oscillations in tool-part system based on the work of motor-spindle.

5. To identify the best option of the rotary mechanism according to required rigidity.

Scientific novelty

1. We designed a dynamic model of the four-coordinate milling machine for processing of the large-size wooden products that allows us to determine the frequencies spectrum and the amplitudes of tools and products vibration in the work area, characterized by the addition of the four rotating coordinates on the three axis milling machine.

2. We designed a model of creating waves on the machined surface of the product caused by elastic systems vibrations of the tool and a support. It shows that the milling operating mode for a developed mechanism occurs around a resonant zone of response characteristic with a little dynamic coefficient. The roughness of a machined surface does not exceed the allowable values due to vibrations. It indicates about the optimality of mechanism rigidity.

Practical value of the work

This rotary device increases the accuracy of processing of parts on the machine; as a result flight characteristics of pilotless aircrafts are improved. Also processing time is reduced.

Personal author's contribution to the research is developing fundamentals that define the scientific novelty and practical significance in determining the goals and objectives of the work. The main scientific results are obtained by the author.

Work approbation:

1. Research and practical conference “Youth and Science” (Siberian Federal University, Krasnoyarsk, 2013);

2. The Xth international student research and practical teleconference «Scientific community of the 21st century students» (Novosibirsk 2013);

3. The XII international research and practical teleconference «Progressive processes of scientific knowledge of the world in the 21st century» (Kazan 2014);

4. Workshops of the department of design - engineering support of machinery production (Polytechnic Institute, Siberian Federal University).

Publications

Four articles based on the obtained results of the thesis were published.

THE MAIN CONTENT OF THE THESIS

In the introduction the topicality of research problems of the product turning on a three-axis machine and the general characteristic of the problem are described.

In the first chapter we overviewed and analyzed systems of product turning in metal and woodcutting machines. Research of rigidity standards of machines and cutting parameters was done. Original dynamic model of processing on the machine with description of the major influencing factors was considered and the following conclusions were made:

1. In woodworking machines the scheme where turning the product with its attachment to the main spindle and holding the product loose end with rotating center is used.

2. Basic theorize in the field of machines dynamics designed by V. A. Kudinov were considered and, in particular, the dynamics of the cutting process on machine tools was described.

3. A preliminary dynamic model of the wood processing system was proposed, where we took into account the constructive scheme of the machine spindle group of modernized and developed a rotary mechanism of a work piece.

4. Certain requirements for the designed products were identified: turning speed of the work piece corresponds to 7.5 min^{-1}, resolution of the work piece turning is 0.6 deg.min, weight of the work piece with machine - tool attachment is 100 kg, the length of the work piece with a machine - tool attachment is 500 - 2500 mm, the machine - tool attachment must be mounted in three-jaw chuck, the back rotating center should be reset along the length with tolerance equal to 0,1 mm.

In the second chapter we considered the manufacturing technology of pilotless aircrafts using the developed control programs based on PowerMill software. The particular sequence of processing and feeding work piece scheme was identified (Figure3).

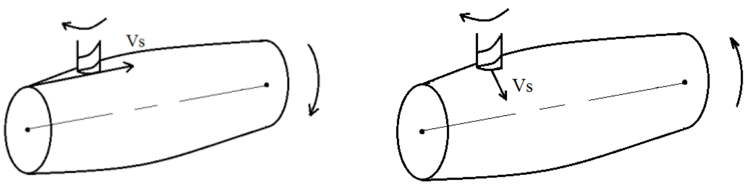

Figure 3 – Longitudinal and transverse blank supply

The accuracy of a surface processing influences on feed rate and frequency of the tool rotation. The roughness of the processed surface depends on the specified modes and the processing scheme. The size, form and the direction of micro roughness depend on methods, modes and the processing scheme.

Increasing reliability of processing with the use of limit depth of cutting and supply can be achieved through elimination of technological overload that normally arise at the moment of cutting-in and cutting-out from the cutting tool. The CNC allows us to change the size of feeding these transitions of a cycle automatically. Performance and reliability are increased due to a rational choice of cutting rate.

The calculation of the modes of cutting wood work piece (I.T.Glebov) is made. The cutting tool is an end milling carbide cutter. During roughing work the diameter of the end milling cutter is equal to 14 mm, the number of teeth is 2. Finishing performance is made with a spherical cutter where d = 6 mm, the number of teeth is 2.

Calculation of the circumferential and the radial cutting force is determined by the following parameters: milling depth, milling width, spindle speed and feeding rate. The objective function is minimization of error processing products. The output parameter is the radial force. Dependent parameters are spindle rate, n r/min, feeding rate, Vs m/min.

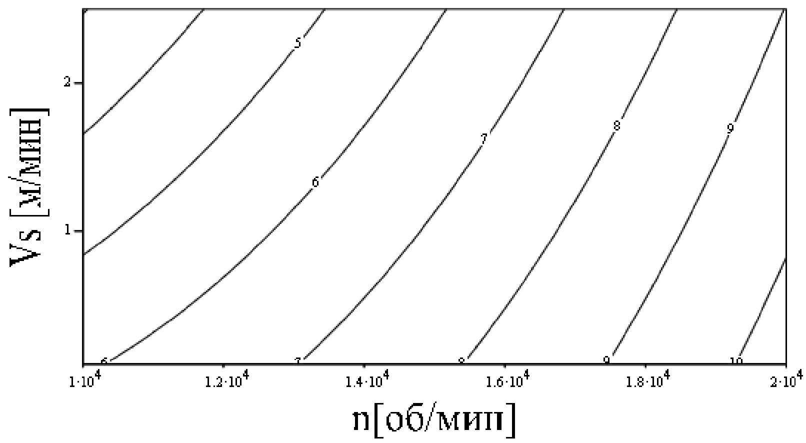

Figure 4 – Dependency of radial cutting force on the rate feeding of the tool and work piece rotating

The graph shows that the radial cutting force is increased due to increasing any of the dependent parameters. The calculations and graphs determine the optimal cutting conditions (Table 1).

Table 1 - Cutting forces

	Roughing processing	Finishing processing
Spindle rates, r/min,	20000	20000
Feeding rate, m/min	2,5	2,5
Circumferential cutting force, N	30	18,17
Radial force, N	9,02	1,64

In the third chapter the development of the rotary mechanism the work piece (RMW) is presented. The RMW consists of the basis 1, the headstock 2 and the tailstock 3.

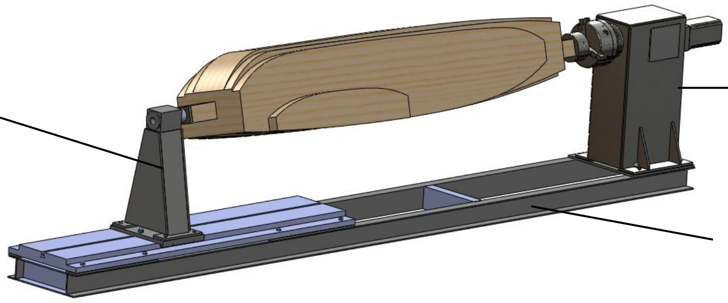

Figure 5 – A rotary mechanism of the work piece

The base consists of a frame and a plate (screwed to the frame).

The frame consists of longitudinal and transverse channels and plates (welded to the channels). Plates should be treated as a single planar surface for mounting the headstock and the plate with the T- shaped groove. Longitudinal channels should be linked cross channels the same profile (two on the sides and two in the middle of the longitudinal channels).

The headstock is made up of a holder, where the work piece is mounted, spindle transmits torque from the engine to the holder and body and fixed to the base. The headstock cross-section is shown in Figure 6.

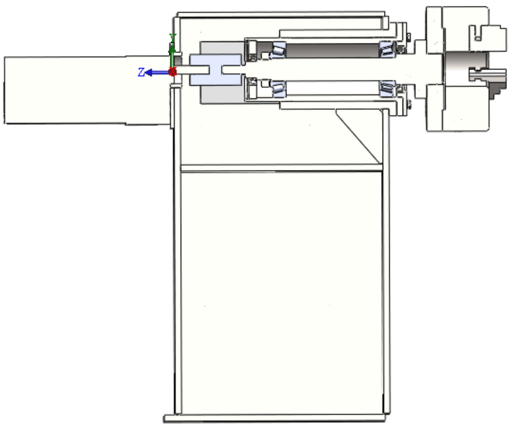

Figure 6 – The headstock

The tailstock consists of a rotating center, which backs the sample and body fixed to the base.

The design is focused on providing the required stiffness of the system.

In the fourth chapter we considered a dynamic model of the four - coordinate milling machine for machining large, wooden samples that allow us to calculate due to determining the spectrum of natural frequencies and amplitudes of vibratory tools and products in the treatment zone.

Based on the analysis of three-axis machine design based on the example of a dynamic model of the tool drive we produced the most malleable part - tool with slide mounted motor spindle (Figure 7).

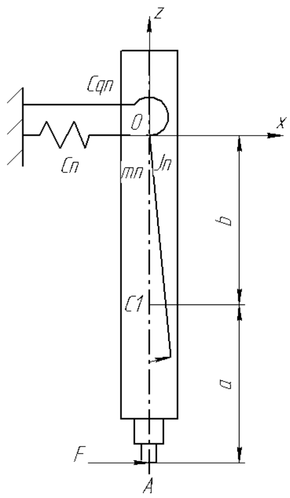

Figure 7 – A dynamic system of tool drive

Where C_1 is the center of mass, O_1 is the center of rigidity.
Dynamic model SRM is presented on Figure 8.

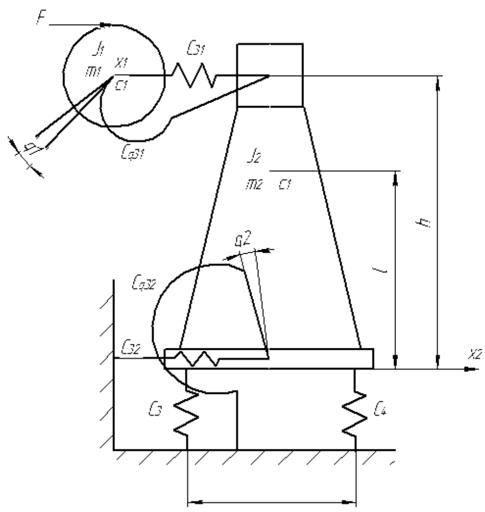

Figure 8 – A dynamic system of a support

Where C_1, C_2 – the center of work piece mass

As a result, the dynamical system consists of six generalized coordinates. The equations of the system motion are presented in a matrix form.

Inertia matrix of the tool dynamic system is the following:

$$A_x = \begin{pmatrix} m_n & m_n a \\ m_n a & J_n + 2m_n a^2 \end{pmatrix} \quad (1)$$

Stiffness matrix of the tool dynamical system is the following:

$$B_x = \begin{pmatrix} C_n & 0 \\ 0 & C_\varphi \end{pmatrix} \quad (2)$$

Inertia matrix of the mechanism dynamic system is the following:

$$A_c := \begin{pmatrix} m_1 & 0 & 0 & 0 \\ 0 & J_1 & 0 & 0 \\ 0 & 0 & m_2 & m_2 l \\ 0 & 0 & m_2 l & J_2 m_2 l^2 \end{pmatrix} \tag{3}$$

Stiffness matrix of the mechanism dynamical system is the following:

$$B_c := \begin{pmatrix} C_{31} & 0 & -C_{31} & -C_{31}h \\ 0 & C_{31} & 0 & -C_{31} \\ -C_{31} & 0 & C_{32} & C_{31}h \\ -C_{31}h & -C_{31} & C_{31}h & C_{31}h^2 + C_{\varphi 32} + C_{\varphi 31} \end{pmatrix} \tag{4}$$

Inertial dynamic system parameters were obtained using complex software SolidWork, elastic - analytically. The results are shown in Table 2.

Table 2 – Rigidity characteristic

The tool		
Cross rigidity	C_n	$1,87 * 10^6 N/m$
Angular rigidity	C_φ	$1,63 * 10^8 \frac{N * m}{rad}$
The sample rotary mechanism		
Sample cross rigidity	C_{31}	$1,11 * 10^5 N/m$
Sample angular rigidity	$C_{\varphi 31}$	$4,4 * 10^3 \frac{N * m}{rad}$
The mechanism cross rigidity	C_{32}	$7,67 * 10^9 N/m$
The mechanism angular rigidity	$C_{\varphi 32}$	$1,8 * 10^8 \frac{N * m}{rad}$

Rigidity of the headstock and the tailstock in the three axes under the action of a single load in a software environment Ansys are calculated (Table 3).

Table 3 - Rigidity of the headstock and the tailstock rigidity by the unit load

Axis of loading force	Headstock		Tailstock	
	Movement, mm	Rigidity, $\frac{kN}{mm}$	Movement, mm	Rigidity, $\frac{kN}{mm}$
x	$1,5 * 10^{-2}$	67	0,29	3,44
y	$3,07 * 10^{-3}$	325,73	0,36	2,78
z	$8,5 * 10^{-3}$	$j_z = 117,64$	0,05	20

A simplified dynamic model of a product rotary mechanism can be presented in the form of transfer functions shown in Figure 9.

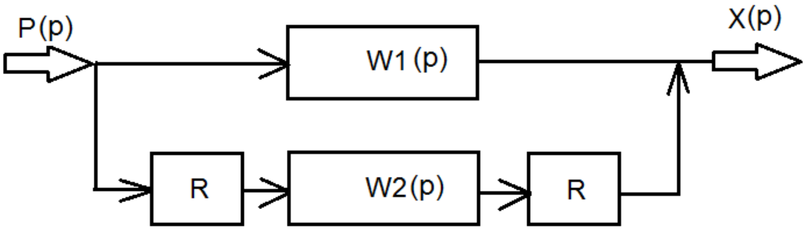

Figure 8 – Dinamic model of the rotary mechanism: W1(p) and W2(p) –transfer functions of the transverse and angle elastic systems of the product and mechanism; R – radius of the impact application point, P(p); X(p) – elastic displacement of the system

We determined the natural frequencies and amplitudes of the system tools and mechanism forced vibrations by modal analysis (Figure 9) with the formula:

$$A(p) = \sqrt{U(p)^2 + N(p)^2} \qquad (5)$$

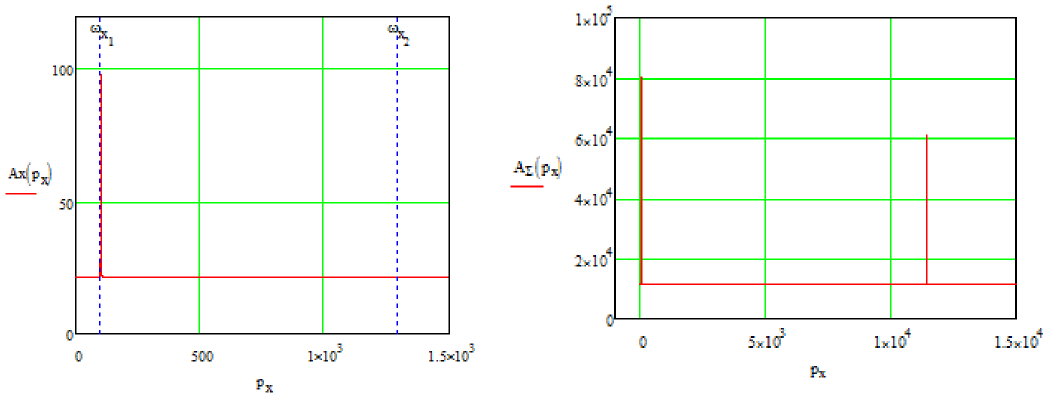

Figure 10 - The frequency response of the tools and mechanism systems

On the basis of the obtained results we optimize processing accuracy. Surface roughness is characterized by the numerical values of roughness parameters. The values of the irregularity parameters is in range of 2,5 ... 1600 microns.

The objective function is the roughness of the machined surface. Variable parameters are the feed rate of the tool system and rigidity. Vibration during milling causes a relative displacement of the tool and the product due to the deformation of elastic systems of spindle and a support. On the treated surface the waves arise, which step can be determined due to the following equation:

$$l_B = \frac{V_s}{f_{sp}} \qquad (6)$$

Where $V_s -$ feedrate, mm/s; f_{sp} – oscillation frequency, Hz. The wave depth is determined by the total amplitude oscillations of the spindle system and a support at the point of dynamic effects. The total roughness $R_a = 230{,}827\ mcm$, which does not exceed the allowable values.

THE MAIN RESULTS AND CONCLUSION

1. Workflow characteristics of cutting pilotless aircrafts wooden products by end mill, the requirements for the kinematic characteristics, rigidity and accuracy were identified.

2. The sample rotary mechanism with the optimization of was developed.

3. A software module of automated calculation of the optimum cutting wooden was made.

4. The dynamic model to determine its elastic- inertial parameters using a PC "ANSYS" was developed.

5. The Eigen values of the dynamic system and frequency response of a dynamic system with external harmonic indignation were calculated.

6. The best option of the samples swinging mechanism required rigidity was identified.

7. A software module of the automated calculation of natural frequencies and amplitudes of forced vibrations was made.

8. The optimum design of the sample rotary mechanism by criterion of the stiffness was revealed.

FUNDAMENTALS OF THE THEISES ARE PUBLISHED IN THE FOLLOWING SCIENTIFIC JOURNALS:

In journals approved by Russian Academy of Science:

1. Vedrova S. A. Calculation and optimization of woodworking of pilotless aircrafts parts //Integration of worldwide scientific processes as foundation society progress: proceedings of the XII international research and practical teleconference «Progressive processes of scientific knowledge of the world in the 21st century» (Kazan, 2014)

2. Vedrova S. A. Calculation of the dynamic characteristics of the mechanism of rotating work pieces on the three-coordinate milling machine // International research journal, № 5 (Ekaterinburg, 2014).

In other journals:

3. Vedrova S. A. Analysis of the mechanisms of rotary work piece used in woodworking CNC machines and their rigidity // proceedings of the Xth international student research and practical teleconference «Scientific community of the 21st century students» (Novosibirsk 2013).

4. Vedrova S. A. Designing rotary work piece used in the woodworking machinery CNC // proceedings of research and practical conference “Youth and Science” (Siberian Federal University, Krasnoyarsk, 2013).