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Improving of Vibration Resistance of Boring Tools by Big Diameter Holes Tooling on Lathe

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Abstract

This paper presents a mathematical model of vibratory displacement of the toll point under the action of variable forces with regard to the application of the developed tooling system. A three-dimensional model was also created, on the base of which the design of the tooling system was developed. As a result graphs of vibratory displacement of the toll point were obtained, which allow us to judge about the decrease of vibration amplitude in the cutting process. The conducted experimental studies have shown the increased vibration resistance of boring tools when using the developed tooling system. Decreasing of the vibration amplitude by cutting process can improve the quality of the machined surface.

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Keywords: boring tool; tooling system; a three-dimensional model; the vibration resistance; the vibration amplitude.

1. Introduction

The analysis of cutting action of rolling, mining, power machinery details shows that effective heavy hole machining in details of liner and cylinder type is an important task. Work pieces for such details are solid and broached forgings, and also castings which are made with large stocks for machinery. And, often, similar parts are not only machined on hard milling-boring group lathes, but on turning lathes-too.

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The process of hole-making operation on turning lathes by boring tools is complicated by unfavourable terms of cutting, related to large tool extension that conduces to the loss of chatter stability of tool piece. The higher indicated terms of hole machining of large size and length conduce to the considerable decline of parameters of exactness and quality of the processed surfaces [1, 4].

In the process of boring the length of machinery or the hole depth determines the tool extension, and during the work with large extension of boring tool a large bending of its tool holder in relation to fixing in tool block appears, that results in considerable deformations and dynamic loading of the tool. An increase of inflexibility of the resilient system of «lathe-tool-instrument-detail» is one of the basic methods of removal of impermissible vibrations.

By boring holes in the details of relatively large diameter, work pieces for which are forgings or founding, with relatively large unevenness of stocks, a changeability of size and point of appendix of cutting force appears. Changes in deformation time are frequently impossible to compensate by corresponding size setting or resetting.

Therefore the actual task which can be solved by the development of the special instrumental system for boring of relatively large holes on turning lathes.

2. Modelling of boring tool vibrations

We will consider the action of cutting forces on boring tool with enough length of cantilever part of tool-holder. Taking into account that the resulting vector of force P from cutting force component is inclined under a corner α in relation to the vertical axis of Z, for determination of moving of extreme point of cutting edge of the tool it is possible to apply the formulas of theory of resistance of materials for the so-called unsymmetrical bending.

An unsymmetrical bending is one of the types of compound bending at which an arising in cross runners a flexion moment does not lie in any of main planes of inertia, and, can be decomposed on two rectangular components in main planes inertias. Thus, an unsymmetrical bending can be examined as a combination of two flat cross-bending in the main planes of inertia [5]. Following papers describe the vibration stability in more detail [6-11]. The effect of unsymmetrical bending on the tool holder of the boring tool of the rectangular cross-section is shown on Fig. 1.

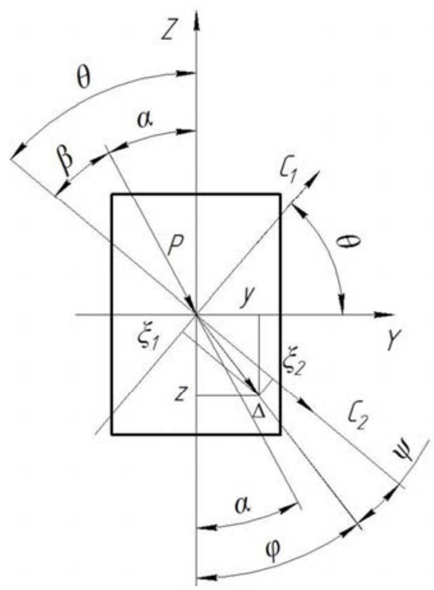

Fig. 1. Cross section of the tool-holder that experiences an unsymmetrical bending.

The notations used in the figure 1:

C1 – axis of minimum stiffness; C2 is the axis of maximum stiffness;

y – projection of the direction of the full deflection of Δ on Y-axis; z – projection of the direction of the full deflection of Δ on Z; ξ1- projection of the directions of the full deflection Δ on the axis of minimum stiffness C1; ξ2- projection of the direction of the full deflection Δ on the axis of maximum stiffness C2; ψ – the angle between the warp direction and the axis of maximum stiffness C2; α – the angle between Z axis and the direction of action of result force; β – the angle between the direction of the axis of maximum stiffness C2 and the direction of resultforce action P; φ - the angle between the direction of deformation Δ and Z-axis, θ - the angle between the direction of the axis of maximum stiffness C2 and Z axis.

Now let us turn to the dynamic model of the elastic system of the boring tool – lathe carriage in the plane perpendicular to the axis of the lathe centers, which can be represented in the form of two springs, oriented at some angle to the coordinate system (Fig. 2).

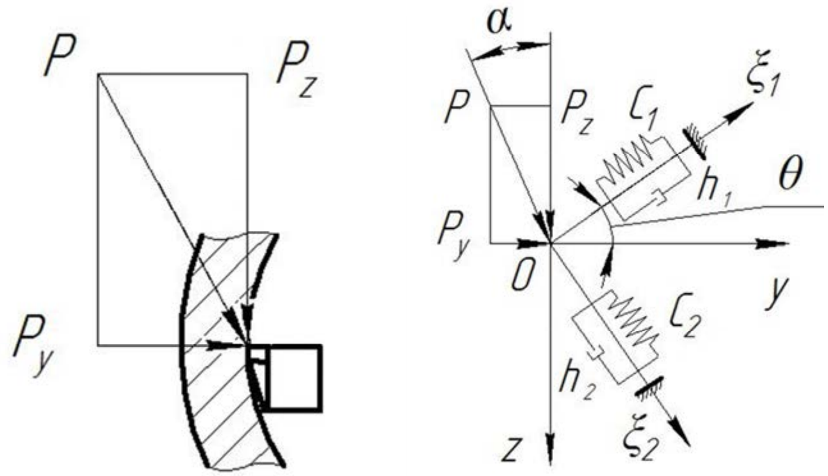

Fig. 2. Scheme of cutting forces action on the elastic system of the boring tool – lathe carriage in the YZ plane.

This model of the elastic system allows solving two main tasks. First of all, the elastic displacement of the top of the boring tool in the radial and tangential directions under the action of the cutting force can be determined.

Secondly, the analysis model of the elastic system allows determining the restoring forces, i.e. the elastic forces arising from the deviation of the top of the boring tool from the position of static equilibrium considering damping. The forces of elasticity, as will be shown, are the components of the dynamic forces and largely determine the stability of cutting process [12, 13].

To solve the task of determining the elastic displacement of the top of the boring tool under the action of cutting forces, we’ll find the coefficients of the compliance system the boring tool - carriage. For this purpose we’ll define the displacement of the top of the boring tool under the action of a single force P_1 acting along Y-axis projection of this force on the principal axes of the stiffness.

$$P_{\xi 1} = P_1 \cdot \cos\theta = \cos\theta \tag{1}$$

$$P_{\xi 2} = P_1 \cdot \sin\theta = \sin\theta \tag{2}$$

Displacement in the direction of the axes of stiffness

$$\xi_1' = \frac{P_{\xi 1}}{C_1} = \frac{\cos\theta}{C_1} \tag{3}$$

$$\xi_2' = \frac{P_{\xi 2}}{C_2} = \frac{\sin\theta}{C_2} \tag{4}$$

Coordinates $\xi_1$and ξ_2 are associated with the coordinates y and z by following relations

$$y = \xi_1' \cdot \cos\theta + \xi_2' \cdot \sin\theta \tag{5}$$

$$z = \xi_2' \cdot \cos\theta - \xi_1' \cdot \sin\theta \tag{6}$$

Substituting the values ξ_1 and ξ_2 we'll find

$$y = \frac{\cos^2\theta}{C_1} + \frac{\sin^2\theta}{C_2} \tag{7}$$

$$z = \frac{1}{2}(\frac{1}{C_2} - \frac{1}{C_1})\cdot \sin 2\theta \tag{8}$$

Since the displacement y is caused by unit force P_1 aimed along the y-axis, this displacement has the flexibility factor s_{11}. Displacement Z caused by a unit force P_1, then z has the flexibility factor s_{21}, i.e. we can write

$$s_{11} = \frac{\cos^2\theta}{C_1} + \frac{\sin^2\theta}{C_2} \tag{9}$$

$$s_{21} = \frac{1}{2}(\frac{1}{C_2} - \frac{1}{C_1})\cdot \sin 2\theta \tag{10}$$

Arguing similarly, we'll find the displacement under the action of a single force directed along the axis z, i.e. the coefficients of the compliance along the z-axis can be written:

$$s_{11} = \frac{\cos^2\theta}{C_2} + \frac{\sin^2\theta}{C_1} \tag{11}$$

$$s_{12} = \frac{1}{2}(\frac{1}{C_2} - \frac{1}{C_1}) \cdot \sin 2\theta \tag{12}$$

The expressions of the compliance coefficients allow us to determine the elastic displacement of the top of the boring tool, if the components of the cutting forces along the coordinate axes P_y and $P_z$are known. The total displacement in the radial direction under the action of the components P_Y and P_z is thus the sum of

$$y' = s_{11} \cdot P_y + s_{12} \cdot P_z \tag{13}$$

Arguing similarly, we'll find the elastic displacement of the top of the boring tool in the tangential direction

$$z' = s_{21} \cdot P_y + s_{22} \cdot P_z + s_{22} \cdot P_z \tag{14}$$

Not only cutting forces and friction forces coming from the chip on the front surface and the force of the introduction and friction on the treated surface on the back surface act on the working part of the tool. Forces on the front surface of the instrument are proportional to the surface area of the shear layer, and the forces on the back surface depend on the area of contact of the tool with the detail and the direction of their relative displacement, i.e. the vector of the actual cutting speed, which is determined by the vector sum of cutting speed and relative speeds of the vibrations of the tool in the directions of the coordinate axes Y and Z. In addition to these forces, which are internal, the external forces, which are divided into a pulse having a random character, and harmonic disturbances act on the system too. Random changes of hardness of the processed material, the changes in the allowance, other power pulses relate to impulse effects. All these types of effects on the instrument cause its deflection from the initial position determined by the characteristics of the elastic system of the instrument. Cutting forces cause the tendency of the tool from the detail, which leads to a reduction of the thickness of the cutting layer, or, in case of unfavourable orientation of the axes of stiffness, buckling. Pulse exposures give rise to transients, duration of which is determined by the dissipative properties of the system, and the amplitude and frequency of repetitions depends on the intensity of random effects.

As in real cutting process the impact of these entire species takes place, the resulting oscillations of the tool also will be determined by the joint response of the system to these impacts. In general form this can be represented as a sequence of transients movements to steady-state oscillations of the system. The timing sequence of pulses is described by a random distribution law, and the appearance of oscillations in the transition process is determined by the characteristics of the elastic system of the instrument, its design parameters, cutting conditions and amount of wear. The cutting edge of the tool in cross section always has the radius of rounding, which connects the front and back surfaces. On the front surface of the tool chips removed from the detail descends, and on the back surface frictional contact with the processed surface due to the elastic recovery takes place. On the curved part of the cutting edge area in which there is a separation of the processed material to the chip, converging on the front surface, and the treated surface of the part. Having defined relative vibrations along the axes Y and Z, and knowing the position of the point of separation, it is possible to calculate the displacements in radial and tangential direction for this point on the radius of rounding of the cutting edge. Fluctuations in the tangential direction will determine the change in the sign and magnitude of the shear stresses. Power P_y acting on the back face of the boring tool also has a non-linear change of the contact pressure in the presence of the relative fluctuations and flank wear. Thus, the equation of motion of the top of the cutter with the given mass m and damping coefficients h_1 and h_2 can be represented as follows:

$$\begin{cases} m \cdot \ddot{\xi}_1 + h_1 \cdot \dot{\xi}_1 + c_1 \cdot \xi_1 = Py \cdot \sin\theta + Pz \cdot \cos\theta \\ m \cdot \ddot{\xi}_2 + h_2 \cdot \dot{\xi}_2 + c_2 \cdot \xi_2 = Py \cdot \cos\theta + Pz \cdot \sin\theta \end{cases} \tag{15}$$

We'll write the formulas of transition from axes ξ_1 and $\xi_2$to axes Z and Y:

$$\xi_1 = z \cdot \cos\theta + y \cdot \sin\theta \tag{16}$$

$$\xi_2 = y \cdot \cos\theta + z \cdot \sin\theta \tag{17}$$

After substitution we obtain the following system of equations

$$\begin{cases} \ddot{z} \cdot \cos\theta + \ddot{y} \cdot \sin\theta = [Pz \cdot \cos\theta + Py \cdot \sin\theta - h_1 \cdot (\dot{z} \cdot \cos\theta + \dot{y} \cdot \sin\theta) - c_1(z \cdot \cos\theta + y \cdot \sin\theta)]/m \\ \ddot{y} \cdot \cos\theta + \ddot{z} \cdot \sin\theta = [Pz \cdot \cos\theta - Py \cdot \sin\theta - h_2 \cdot (\dot{y} \cdot \cos\theta - \dot{z} \cdot \sin\theta) - c_2(y \cdot \cos\theta + y \cdot \sin\theta)]/m \end{cases} \tag{18}$$

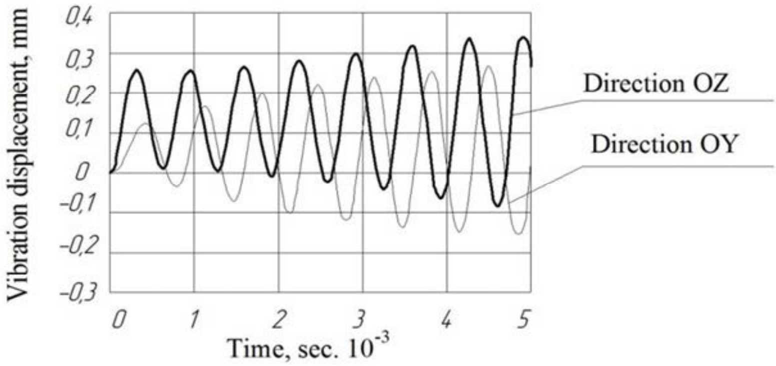

Fig. 3. View of the relative fluctuations when θ=30°.

These equations were solved by numerical method using a computer system of performing mathematical calculations MATLAB. Depending on the characteristics of the elastic system and the applied external forces damped or self-excited oscillations with different duration of the transition process are obtained. In the subsequent figures the results of the calculation are presented. Fig.3 shows the form of the motion of the original system with the following parameters for θ=30°. When solving the system of equations the relative displacements of axes Y and Z are determined. For the case of stepwise application of the cutting force P_z from cross-sectional slice to the top of the insert with the mass m. If the value of the orientation angle of the axes of stiffness θ = 30°, then the system is unstable, i.e. the amplitude of oscillation increases.

With the introduction of additional stiffness, the angle of orientation of the axes of stiffness is reduced to the angle θ=15°. Additional stiffness may be obtained by use of special tooling system [14-16], which creates a movable support for the tool holder boring tool near the top of the tool (fig. 4). In this case the oscillations are decaying and gradually approach to steady-state values equal to the corresponding static deformations (fig. 5).

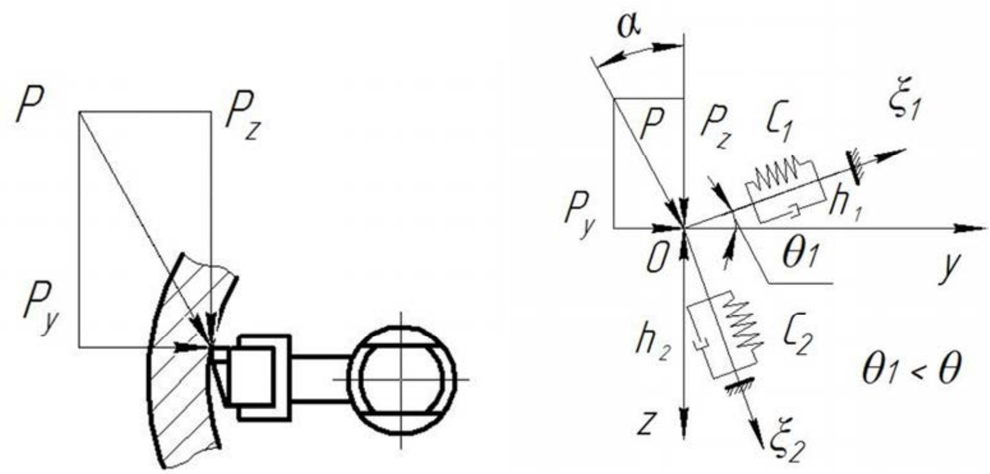

Fig. 4. A diagram of the steps of cutting forces on elastic tooling system – lathe carriage in YZ plane.

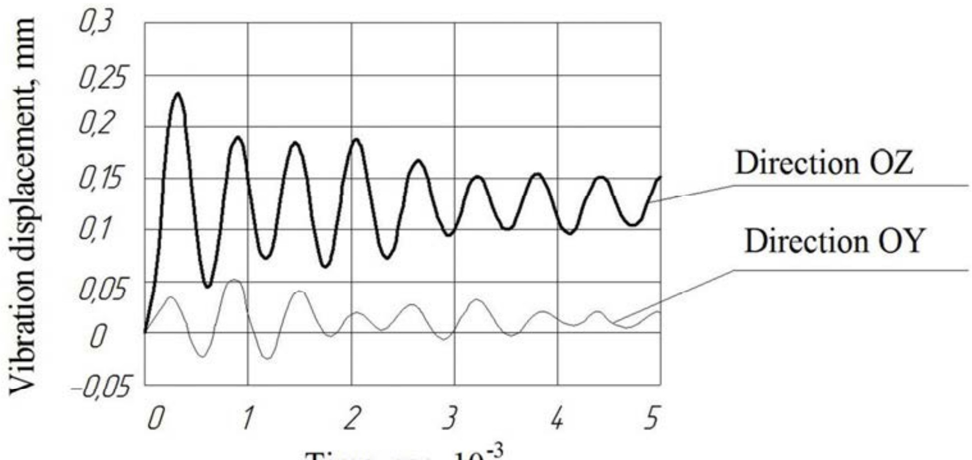

Fig. 5. View of the relative fluctuations when θ=15°

The developed model allows calculating the parameters of the relative fluctuations of the detail and the tool, based on the parameters of the elastic system and cutting process.

3. Results and discussion

On the basis of the proposed scheme of increasing the stiffness and vibration resistance by boring, three-dimensional model of the tooling system, which creates additional movable tool support, was developed [17, 18]. On the base of three-dimensional model the tooling system was designed (fig. 6).

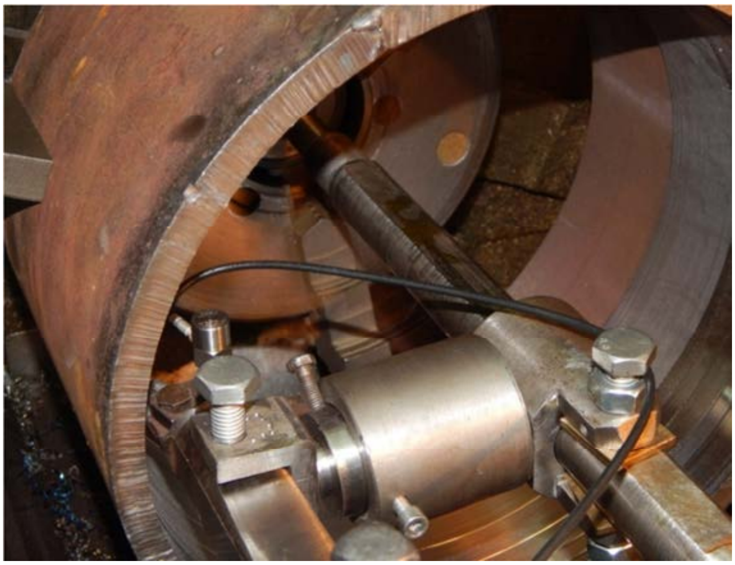

Fig. 6. Design of the tooling system

The amplitude of vibrations of the boring tool by the same cutting conditions using the developed tooling system and without it, resulting experimental studies are presented in Table 1.

Table 1 The amplitude in OZ and OY at various extension of the holder, mm

	The amplitude in OZ and OY at various extensions of the holder, mm					
	100		150		200	
	OZ	OY	OZ	OY	OZ	OY
Boring tool section 25x25 mm	0,091	0,035	0,208	0,073	0,442	0,157
Boring tool section 30x30мм	0,077	0,027	0,184	0,064	0,242	0,078
Tooling system,boring tool section 25x25mm	0,073	0,023	0,108	0,034	0,156	0,054
Tooling system,boring tool section 30x30мм	0,065	0,021	0,094	0,028	0,121	0,035

Also, experiments were conducted on the effect of vibration amplitude on the surface quality. It was found that the value of surface roughness will decrease by 40-60%, while reducing the amplitude of vibration of the cutting edge of the tool relative to the work surface. Additional work on heavy lathes operations is discussed in [19-26].

4. Conclusion

Based on the results of modelling and experimental studies it can be concluded that the increase in the stiffness of the boring tool by application of the developed tooling system leads to increased vibration resistance of the boring process. By reducing the vibration amplitude of the boring tool top improves the quality of the machined surface. Cutting forces and friction forces which are coming from the chip on the front surface as well as the the force of the introduction and friction on the treated surface on the back surface both act on the working part of the tool. Reduction of the thickness of the cutting layer, in case of unfavorable orientation of the axes of stiffness, buckling, are a consequence of cutting forces that cause the tendency of the tool from the detail.

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