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DYNAMIC MODEL OF THE TECHNOLOGICAL BORING SYSTEM

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Abstract. The dynamic model of the boring process has been developed, which takes into account the basic dynamic properties of the technological system of the processing process, tool wear and deviations of the workpiece shape from the nominal parameters, taking into account the peculiarities of two-component control.

ДИНАМИЧЕСКАЯ МОДЕЛЬ ТЕХНОЛОГИЧЕСКОЙ СИСТЕМЫ РАСТАЧИВАНИЯ

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Ключевые слова: растачивание, управление, возмущения, динамика.

Аннотация. Разработана динамическая модель процесса растачивания, учитывающая основные динамические свойства технологической системы процесса обработки, износ инструмента и отклонения формы заготовки от номинальных параметров с учетом особенностей двухкомпонентного управления.

The current state of the economy brings to the fore the problems associated with the production of competitive mechanical engineering products. In turn, the high level of requirements for modern machines has led to a number of problems associated with the technology of processing machine parts. An increase in the physical and mechanical characteristics of strength, hardness and wear resistance of structural materials determined the general trend towards a decrease in their machinability, which leads to increased tool wear, increased forces, deformations and cutting temperature, and, consequently, to a decrease in processing accuracy and quality of machined surfaces. Many problems are caused by the design features of machine parts. The constant striving to reduce the material consumption of structures leads to a decrease in the rigidity and vibration resistance of parts during processing. Deviations in the shape of parts cause uneven elastic deformations during cutting and the corresponding processing errors. For these conditions, technologies based on the removal of thin chips are of particular relevance, which ensures low cutting forces, deformation of parts and their high accuracy.

General machining problems are initially exacerbated by the process of making accurate holes due to unfavorable cutting conditions and reduced tool stiffness.

This task is especially relevant for machining precise holes when boring on boring machines. The widespread use of the boring operation is due to the fact that it allows for high productivity and accuracy in the size and shape of holes. On the other hand, the lack of dynamic models that take into account the influence of external disturbances on the dynamics of the process leads to ineffective use of modern equipment and limits its capabilities.

The purpose of this work is to build a dynamic model of the boring technological system (TS), taking into account the influence of disturbances on the output indicators of the process.

The boring technological process (TP) is impossible without the force interaction of the workpiece to be machined and the toolFor this, it is necessary to provide a mechanical (power) connection between the main elements of the technological system for its implementation - a tool and a workpiece. This connection is one-way (unrestrained) [1]. The condition that characterizes it is represented by the ratio:

$$L(\tau) \le R(\tau) - r(\tau)\,, \tag{1}$$

where $L(\tau)$ – the current distance between the axis of the hole being machined and the boring bar mounting base, from which the position of the cutter tip is counted, $r(\tau)$ – current radius of the hole being machined; $R(\tau)$ - the current value of the position of the tool tip relative to the base.

Vectors $R(\tau)$ and $r(\tau)$, can be presented in the form:

$$\begin{cases} R(\tau) = R_0 + \Delta R(\tau) \\ r(\tau) = r_0 + \Delta r(\tau) \end{cases},$$

where $R_0 = const_1$, $r_0 = const_2$; $\Delta R(\tau)$, $\Delta r(\tau)$ – initial values of the corresponding parameters and deviations from them for the current values of the states of the tool and the machined hole.

Components $\Delta r(\tau)$ and $\Delta R(\tau)$ are: deviations from the shape of the hole and the error in the shape of the tool – $\Delta R_{\Phi}(\tau)$ and $\Delta r_{\Phi}(\tau)$; $\Delta R_u(\tau)$ and $\Delta r_c(\tau)$ – changes in the current dimensions of the workpiece and tool due to the removal of part of the allowance and wear; dimensional changes due to heating and expansion – $\Delta R_{t^o}(\tau)$ and $\Delta r_{t^o}(\tau)$, and also due to elastic deformations of the bodies of the tool and the workpiece during TP – $\Delta R_y(\tau)$ and $\Delta r_y(\tau)$, respectively, i.e.

$$\begin{cases} \Delta R(\tau) = \Delta R_{\Phi}(\tau) - \Delta R_u(\tau) + \Delta R_{t^o}(\tau) - \Delta R_y(\tau) \\ \Delta r(\tau) = \Delta r_{\Phi}(\tau) - \Delta r_c(\tau) + \Delta r_{t^o}(\tau) - \Delta r_y(\tau) \end{cases} \tag{2}$$

The second and third terms in each of the equations of system (2) represent relatively slowly changing, or rather accurately predicted values, which makes it possible to take them into account when evaluating the values $R_0(\tau)$, and $r_0(\tau)$.

When describing the cutting zone as a dynamic element of a mechanical system, of interest are those characteristics that determine the possibility of accumulating potential and kinetic energy in the object under consideration due to the movement of the tool and the workpiece as solid bodies, as well as the ability to dissipate (dissipate) the stored energy.

For physical reasons, the existence of such a zone is possible only if the depth of such a zone t_f is a positive value, which corresponds to the conditions for the fulfillment of inequality (1) and makes it possible to rewrite it in the form of the following system:

$$\begin{cases} t_f = R(\tau) - r(\tau) - L(\tau) \\ t_f > 0 \end{cases} \quad (3)$$

The first of the equations of system (3) can be considered as a formal representation of the description of the retaining bond, and the second characterizes the condition of its existence. This makes it possible to apply classical methods of theoretical mechanics to construct a calculation scheme for modeling the dynamics of displacements of a tool and a workpiece as elements of the mechanical equivalent of a vehicle. Without a significant error in the calculations, you can neglect the amount (fraction) of the substance in the cutting zone in relation to the masses of the workpiece and tool. It is also possible not to take into account the influence of the chips and wear products of the cutting tool separating from the workpiece and the tool on the dynamics of the vehicle TS.

The design scheme for analyzing TS is shown in Figure 1.

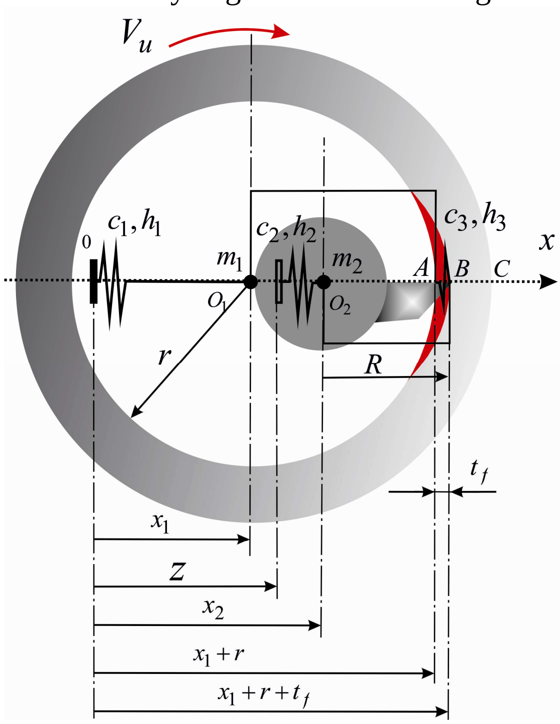

Fig. 1. Design diagram of the boring process

The following designations were used in the modeling: m_1 and m_2 – tool and workpiece masses with coordinates x_1 and x_2, respectively, counted relative to the coordinate system stationary during processing, associated with the machine; c_1 and c_2 – the rigidity of the workpiece and the boring bar; h_1 and h_2 – linear damping coefficients characterizing the indicators of energy dissipation of the considered elements from the speed of their displacement; c_3, h_3 – equivalent stiffness and damping coefficient of the cutting zone; V_u and V_k – linear velocities of workpiece and tool surfaces, respectively; z – distance between the movable support of the boring bar and the machine body.

With constant feed on the machine limb value $z(\tau)$ defined as

$$z(\tau)=\int_{\tau_0}^{\tau} s(t)\cdot dt = z(\tau)\Big|_{\tau=\tau_0} + s\cdot(\tau-\tau_0)\,,\ z_0 = z(\tau)\Big|_{\tau=\tau_0}$$

It is advisable to characterize the state of the vehicle depending on the value t_f, determined from (3), and, taking into account the designations adopted in the design scheme, rewritten in the form:

$$t_f = r - R - (x_2 - x_1)\,. \qquad (4)$$

When describing the dynamic characteristics of the TS, the TS mode, in which $t_f < 0$ not of interest. By virtue of (3), it corresponds to either the absence or termination of contact between the tool and the workpiece being processed. In this case, the TP either has not started yet, or is interrupted, and the dynamic system considered as the carrier of TP properties corresponds to two unrelated systems with independent descriptions: the tool subsystem and the workpiece subsystem, in the behavior of which there are no signs characteristic of the processing process, i.e. its signs do not correspond to the characteristics of TP flow. The movement of each of these subsystems is carried out independently of each other, is determined by external influences and the corresponding initial parameters.

Condition fulfillment $t_f = 0$, corresponds to the moment the tool touches the workpiece. In this way the condition $x_2 - x_1 = r - R$, taking into account (4) and (3), can be represented in the form:

$$[x_1(\tau) - x_2(\tau) - \Delta r(\tau) + \Delta R(\tau)]\Big|_{t_f=0} = r_0 - R_0\,.$$

Depending on the sign of the speed of convergence of the centers of the tool and the workpiece $s(\tau)$

$$\frac{d[x_2(\tau) - x_1(\tau) + \Delta r(\tau) - \Delta R(\tau)]}{d\tau}\Big|_{t_f=0} > 0\,,$$

which can be represented as:

$$\left\{\frac{d[\Delta r(\tau) - \Delta R(\tau)]}{dL(\tau)}\right\}\Big|_{t_f=0} < 1\,. \qquad (5)$$

Relation (5) can serve both to determine the time of the beginning of the touch, and, taking into account (4) and (5), - the angular positions of the tool ($\varphi_{1,0}$) and blanks ($\varphi_{2,0}$).

It can also be useful for determining constraints when choosing feed modes depending on the errors of the initial shapes of the part and tool.

When constructing the statistical characteristics of the descriptions of the forms, these relations allow one to construct the functions of the distribution densities of the considered quantities.

Failure to comply with the relations (5) corresponds to the termination of contact and separation of the tool from the part. If in the future the rate of change in the distance between the axis of the hole being machined and the mounting base of the boring bar does not change sign, condition (5) may start to be fulfilled again, which corresponds to multiple touches of the tool with the workpiece.

The state of the nominal processing mode is characterized by the condition TC $t_f = t_{f_{noml}} > 0$. When developing software control, for example, for CNC machines, deviations from the calculated dimensions of the tool and workpiece are usually considered absent. ($\Delta R_{\Phi} = 0$ и $\Delta r_{\Phi} = 0$). In this case, it is considered that both the workpiece and the tool do not have imbalances, tool wear corresponds to technological standards, material removal corresponds to the design parameters.

Based on (4), taking into account (2), under the above conditions, the depth of cut is determined as:

$$t_f(\tau) = x_2(\tau) - x_1(\tau) + r_0(\tau) - R_0(\tau). \quad (6)$$

There are two variables in relation (6), i.e. the system under consideration has two degrees of freedom.

In accordance with the design model, the position of the point B in the coordinate systems associated with the workpiece and the tool will be determined as

$$x_B = x_1 + r + t_f \text{ and } x_B = x_2 + R,$$

respectively, which makes it possible to determine the depth of the cutting zone as

$$t_f = x_2 - x_1 + (r - R). \quad (7)$$

Using the d'Alembert principle in constructing a dynamic description of the TS, one can characterize the force balance and, taking into account (7), present the results in the form of a state space:

$$\begin{cases} m_1 \cdot \dfrac{d^2 x_1}{d\tau^2} + h_1 \cdot \dfrac{dx_1}{d\tau} + c_1 \cdot x_1 = h_3 \cdot \dfrac{d(x_2 - x_1 + \Delta r(\tau) - \Delta R(\tau))}{d\tau} + \\ + c_3 \cdot (x_2 - x_1 + \Delta r(\tau) - \Delta R(\tau) + r_0 - R_0) \\ m_2 \cdot \dfrac{d^2 x_2}{d\tau^2} + h_2 \cdot \dfrac{dx_2}{d\tau} + c_2 \cdot x_2 = h_2 \cdot \dfrac{ds}{d\tau} + c_2 \cdot s - \\ - h_3 \cdot \dfrac{d(x_2 - x_1 + \Delta r(\tau) - \Delta R(\tau))}{d\tau} - c_3 \cdot (x_2 - x_1 + \Delta r(\tau) - \Delta R(\tau) + r_0 - R_0) \end{cases} \quad (8)$$

Due to the rotation of the workpiece, variations in geometric dimensions have a periodic or almost periodic nature, which explains the appearance of internal exciting forces, which largely determine the dynamics of the turning process.

The constructed relations (8) can serve both for the analysis of the dynamic properties of boring processes, for the construction and correction of programs for CNC machines and the design of new equipment.

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