

DEVELOPMENT OF A MATHEMATICAL MODEL OF THE TURNING OPERATION OF CHARACTERISTIC BEHAVIOR OF THE DYNAMIC SYSTEM IN DEVIATIONS FROM THE NOMINAL MODE

Strelyanaya Yu.O.

Keywords: turning, control, disturbance dynamics.

Abstract. Dynamic model of the process of turning a two-component control. Developed a dynamic model of the process of turning a two-part management, taking into account the dynamic properties of the basic technology of the machining process, tool wear, and deviations from the nominal parameters allowing for the two-component control.

РАЗРАБОТКА МАТЕМАТИЧЕСКОЙ МОДЕЛИ ОПЕРАЦИИ ТОЧЕНИЯ, ХАРАКТЕРИЗУЮЩЕЙ ПОВЕДЕНИЕ ДИНАМИЧЕСКОЙ СИСТЕМЫ В ОТКЛОНЕНИЯХ ОТ НОМИНАЛЬНОГО РЕЖИМА

Стреляная Ю.О.

Ключевые слова: точение, управление, возмущения, динамика.

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

Formulation of the problem. Increasing consumer demands for equipment performance in total naturally tightens the requirements for the parameters of its individual parts. In turn, product quality depends on the parameters of the workpiece processing technology and technological system properties [1].

Constantly increasing demands on surface quality and their geometric dimensions in conditions of inconsistency of the technological system parameters require analysis and consideration of the dynamics of the processing process [2].

Technological operations are traditionally designed using methods not fully responsive to process dynamics influence of disturbing factors which reduces the stability of quality indicators of manufactured products. Processing modes are assigned based on adverse conditions, which reduces productivity and leads to the correction and reconfiguration of the technological system before it requires its actual state. [1].

Analysis of recent research and publications. In existing works, when describing the dynamics of the operation, the processes in the zone of contact of the tool with the part [3] either used simplified processing schemes and to coordinate the results of experiments and modeling, an external periodic disturbing force was introduced [4] which does not correspond to the structure of a dynamic system.

The purpose of this article is to develop a dynamic model of the turning process with two-component control.

Statement of the main material. To build a mathematical model that takes into account the dynamics of the processing process and allows you to automatically adjust the control cycle of the operation of finishing turning, consider the process diagram presented (fig. 1).

$$\begin{cases} m_1 \ddot{x}_1 + h_1 \dot{x}_1 + c_1 x_1 + h_3 \dot{t}_f + c_3 t_f - h_1 \dot{S} - c_1 S = 0 \\ m_2 \ddot{x}_2 + h_2 \dot{x}_2 + c_2 x_2 - h_3 \dot{t}_f - c_3 t_f = 0, \end{cases} \quad (1)$$

here m_1 , m_2 – reduced mass of workpiece with centers and tool with tool holder; h_i and c_i – drag coefficients (damping) and stiffness coefficient i link, respectively; x_1 coordinates of the center of the tool holder and x_2 – coordinate of the center of rotation of the workpiece; S – path traveled by the feed mechanism in time t ; t_f – actual cutting depth.

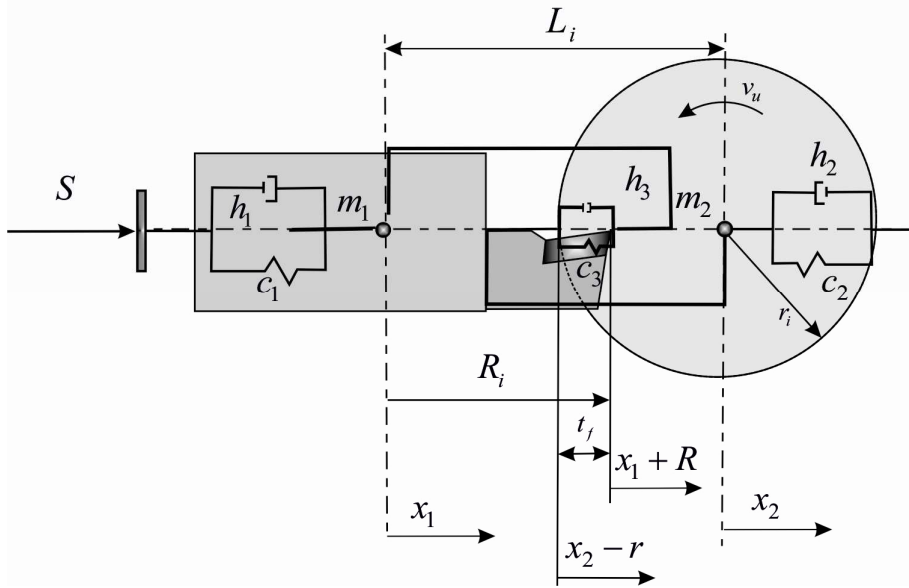


Fig. 2. The design scheme of the dynamic system of the turning process

The actual cutting depth, according to the design scheme (Fig. 2), is defined as

$$t_f = R + r - L, \quad (2)$$

where $R = R_0 + \Delta R$ – the current value of the position of the tip of the cutter, taking into account its wear ΔR ; $r = r_0 + \Delta r$ – current radius vector of the workpiece taking into account material removal and shape deviations Δr ; $L = L_0 + \Delta L = L_0 + x_2 - x_1$ – current distance between the center of the tool holder and the center of rotation of the part.

Given the definition obtained t_f and its constituent elements for the initial position of the workpiece, at the moment of beginning of its contact with the tool ($L_0 = R_0 + r_0$; $S_0 = 0$; $x_{10} = 0$; $x_{20} = 0$; $t_f = 0$) system of equations (1) deviations will be recorded:

$$\begin{cases} m_1 \ddot{x}_1 + h_1 \dot{x}_1 + c_1 x_1 + h_3 (\dot{x}_1 + \Delta \dot{R}) + c_3 (x_1 + \Delta R) - \\ - h_3 (\dot{x}_2 - \Delta \dot{r}) - c_3 (x_2 - \Delta r) - h_1 \dot{S} - c_1 S = 0, \\ m_2 \ddot{x}_2 + h_2 \dot{x}_2 + c_2 x_2 + h_3 (\dot{x}_2 - \Delta \dot{r}) + c_3 (x_2 - \Delta r) - \\ - h_3 (\dot{x}_1 + \Delta \dot{R}) - c_3 (x_1 + \Delta R) = 0. \end{cases} \quad (3)$$

Due to the rotation of the workpiece, variations in geometric dimensions are periodic or almost periodic in nature, which explains the appearance of internal exciting forces that substantially determine the dynamics of the turning process. Model (3) serves as the basis for analyzing the dynamics of the deviation of the process of interaction of the tool with the workpiece from the nominal mode.

To simulate the process, the stiffness and damping coefficients were experimentally determined (table 1).

When determining the static rigidity of the technological system, the workpiece was installed in tensometric centers and brought into contact with the tool. Using the mechanism of transverse feeds, preliminary loading was performed by gradually pressing the tool onto the workpiece. After that, the control loading and unloading of the system was performed. According to the indications of the calibrated amplifier, the loading and unloading forces were determined, and the corresponding displacements in the system were determined by the readings of the linear displacement sensor. The obtained experimental data were processed using the least squares method. The damping coefficient was calculated by the logarithmic attenuation decrement by the method [5]. The mass parameters are taken from the machine data sheet and determined by weighing the workpiece and tool:

Tab. 1. Experimental parameter values for the model machine CTU3500M(H), for steel blanks 40X

№	Наименование	Обозначение	Значение
1	System stiffness coefficient (tool holder)	c_1 , N/m	$(1...5) \cdot 10^9$
2	System stiffness coefficient (workpiece centers)	c_2 , N/m	$(1...18) \cdot 10^{10}$
3	The coefficient of static stiffness of the contact of the tool and the workpiece	c_3 , N/m	$(1...10) \cdot 10^7$
4	System damping coefficient (tool holder)	h_1 , N·s/m	$(2...5,7) \cdot 10^5$
5	System damping coefficient (tool holder)	h_2 N·s/m	$(1,1...5,2) \cdot 10^5$
6	Damping coefficient of contact between tool and workpiece	h_3 N·s/m	$(1,15...1,243) \cdot 10^4$
7	Reduced mass (tool holder)	m_1 , kg	5000
8	Reduced mass (workpiece centers)	m_2 , kg	10000

The processing process for the turning scheme with the following parameters is simulated: $m_1=5000$, $m_2=10000$, $c_1=1e9$ N/m, $c_2=1,5e10$, $c_3=1e7$, $h_1=2,1e5$, $h_2=1,3e5$, $h_3=1e4$, $\Delta R_2=A \sin(wt)$, $\Delta R_1=0$, $\Delta L=5e-5$, $w=20$, $A=5e-5$.

Dependency graphs for tool position deviations x_1 , blanks x_2 and depth of cut t_f from the nominal values are given on fig. 3.

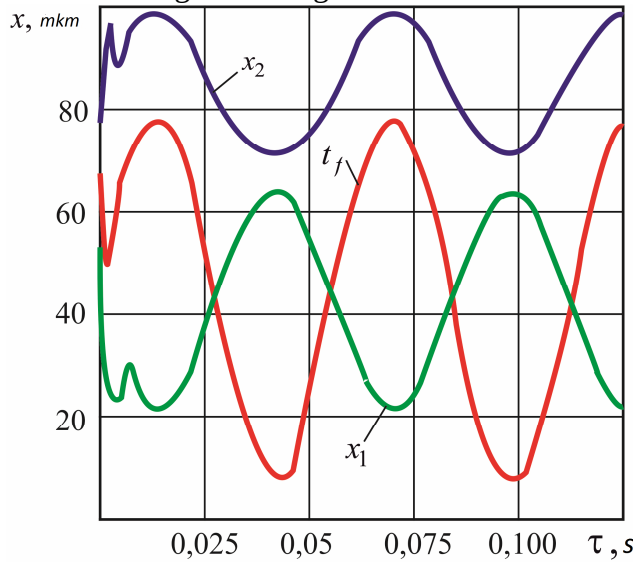


Fig. 3. Dependency graphs for position deviations x_1 , blanks x_2 and depth of cut t_f from the nominal values

Current tool size deviations ΔR and blanks Δr depend on a number of uncontrolled parameters and can be considered realizations of random processes. Values Δr can be measured directly during the processing process, and direct measurements and control of the depth of cut are significantly difficult or almost impossible.

Due to the rotation of the workpiece, variations in geometric dimensions are periodic or almost periodic in nature, which explains the appearance of internal exciting forces that substantially determine the dynamics of the turning process. For further analysis, the dynamic system (3) should be reduced to the form:

$$\left\{ \begin{aligned} \ddot{x}_1 &= \frac{1}{m_1} [-(h_1 + h_3)\dot{x}_1 - (c_1 + c_3)x_1 + h_3\dot{x}_2 + c_3x_2] - \\ &\quad - \frac{1}{m_1} [h_3(\Delta\dot{R} + \Delta\dot{r}) + c_3(\Delta R + \Delta r)] + \frac{1}{m_1} [h_1\dot{S} + c_1S], \\ \ddot{x}_2 &= \frac{1}{m_2} [-(h_2 + h_3)\dot{x}_2 - (c_2 + c_3)x_2 + h_3\dot{x}_1 + c_3x_1] + \\ &\quad + \frac{1}{m_2} [h_3(\Delta\dot{R} + \Delta\dot{r}) + c_3(\Delta R + \Delta r)], \end{aligned} \right. \quad (4)$$

The first terms of the right-hand sides of relations (4) are components with derivatives of deviations of the position of the center of mass of the cutter with the tool holder and the center of rotation of the workpiece, which depend directly on the internal generalized coordinates of the dynamical system (geometric and

kinematic). The second terms reflect the influence of wear on the tip of the cutter and deviations in the shape of the workpiece. The third term of the first equation in system (4) reflects the effect of the cutting path and radial feed of the tool on the dynamic system.

With notation

$$y_1 = x_1, \quad y_2 = \dot{y}_1 = \dot{x}_1, \quad y_3 = x_2, \quad y_4 = \dot{y}_3 = \dot{x}_2 \quad (5)$$

system (4) can be reduced to the normal Koshi form:

$$\left\{ \begin{array}{l} \dot{y}_1 = y_2, \\ \dot{y}_2 = -\frac{1}{m_1}[(c_1 + c_3)y_1 + (h_1 + h_3)y_2 - c_3y_3 - h_3y_4] - \\ -\frac{1}{m_1}[c_3(\Delta R + \Delta r) + h_3(\Delta \dot{R} + \Delta \dot{r})] + \frac{1}{m_1}[h_1\dot{S} + c_1S], \\ \dot{y}_3 = y_4, \\ \dot{y}_4 = -\frac{1}{m_2}[(c_2 + c_3)y_3 + (h_2 + h_3)y_4 - c_3y_1 - h_3y_2] + \\ + \frac{1}{m_2}[c_3(\Delta R + \Delta r) + h_3(\Delta \dot{R} + \Delta \dot{r})]. \end{array} \right. \quad (6)$$

To solve the problems of modeling process dynamics, it is advisable to write relation (6) together with the observation equation.

In the matrix form of the state space, the system takes the form:

$$\begin{aligned} \dot{Y}_0 &= A_0 \cdot Y_0 + B_0 \cdot W + C_0 \cdot U; \\ Z_0 &= E_0 \cdot Y_0 + F_0 \cdot V_0; \\ T_0 &= Q_0 \cdot Z_0, \end{aligned} \quad (7)$$

$$\text{где } A_0 = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -\frac{c_1 + c_3}{m_1} & -\frac{h_1 + h_3}{m_1} & \frac{c_3}{m_1} & \frac{h_3}{m_1} \\ 0 & 0 & 0 & 1 \\ \frac{c_3}{m_2} & \frac{h_3}{m_2} & -\frac{c_2 + c_3}{m_2} & -\frac{h_2 + h_3}{m_2} \end{bmatrix}, \quad \dot{Y}_0 = \begin{bmatrix} \dot{y}_1 \\ \dot{y}_2 \\ \dot{y}_3 \\ \dot{y}_4 \end{bmatrix}, \quad Y_0 = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix},$$

$$U = \begin{bmatrix} S_1 \\ \dot{S}_1 \\ S_2 \\ \dot{S}_2 \end{bmatrix}, \quad B_{01} = \begin{bmatrix} 0 \\ -\frac{c_3}{m_1} \\ 0 \\ \frac{c_3}{m_2} \end{bmatrix}, \quad B_{02} = \begin{bmatrix} 0 \\ \frac{h_3}{m_1} \\ 0 \\ \frac{h_3}{m_2} \end{bmatrix}, \quad C_0 = \begin{bmatrix} 0 & 0 \\ \frac{c_1}{m_1} & \frac{h_1}{m_1} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad W = \begin{bmatrix} W_1 \\ W_2 \end{bmatrix}, \quad U = \begin{bmatrix} S \\ \dot{S} \end{bmatrix},$$

$$W_1 = [\Delta R + \Delta r], \quad W_2 = [\Delta \dot{R} + \Delta \dot{r}], \quad B_0 = [B_{01} \quad B_{02}],$$

Y_0 – Is a vector (column matrix) representing the state vector of the system, $\dot{Y}_0$ – system derivative vector, A_0 – matrix characterizing the dynamic properties of the

system, B_0 – a matrix of parameters for the influence of deviations in the shape of the part and tool, W – state vector of deviations of the shape of the part and tool from the nominal parameters, C_0 – process control matrix, U – vector of control actions associated with the transverse feed.

$$E_0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, F_0 = \begin{bmatrix} f_{11} & f_{12} \\ f_{21} & f_{22} \end{bmatrix}, V_0 = \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}, T_0 = [t_f], Q_0 = \begin{bmatrix} -1 & 1 \end{bmatrix},$$

where E_0, F_0, V_0, T_0, Q_0 – matrix of the state of measurements; matrix of noise intensities of the meters; a matrix of independent Gaussian white noise meters of unit intensity, a matrix of depth of cut, and a matrix for converting aggregate measurements, respectively.

Conclusions and offers. The above relations (7) with designations common to (1), (2), (3), (5) are a dynamic model of the turning process with two-component control, taking into account the main dynamic properties of the technological system of the processing process, tool wear and deviation of the workpiece shape from the nominal parameters, taking into account the features of two-component control.

This approach allows us to separate the requirements for feed mechanisms according to the ranges of regulation and accuracy.

Prospects for further developments in this direction are associated with the construction of diagnostic systems and the development of automatic control systems for technological processes of turning.

References

1. Precision, reliability and performance of metal cutting machines / G.D. Grigoryan, S.A. Zelinsky, G.A. Oborsky, G.F. Firsov. – Kiev: Technics. 1991. – 201 p.
2. Physicomathematical theory of materials processing and engineering technology: 10 vol. Vol. 7: Precision of part processing / F.V. Novikov, A.V. Yakimov, G.V. Novikov, A.A. Yakimov, V.P. Larshin, Yu.N. Krivoshapka, S.A. Ditinenko. G.A. Oborsky, V.M. Tonkonogiy, P.T. Slobodyanik. – Odessa, 2004. – 546 p.
3. Shevchenko A.V. Improving the vibration resistance of turning on a machine with a potentially unstable elastic system cutter-support // Bulletin of the GSTU named after P.O. Sukhoi: scientific and practical journal. – Gomel, 2009. – Issue 1. – P. 10-15.
4. Kudinov V.A. Dynamic calculations of machines (basic provisions // STIN. – 1995. – No. 8. – P. 3-13.

Список литературы

1. Точность, надежность и производительность металлорежущих станков / Г.Д. Григорьян, С.А. Зелинский, Г.А. Оборский, Г.Ф. Фирсов. – Киев: Техніка. 1991. – 201 с.

2. Физико-математическая теория процессов обработки материалов и технологии машиностроения: В 10 т. Т.7: Точность обработки деталей / Ф.В. Новиков, А.В. Якимов, Г.В. Новиков, А.А. Якимов, В.П. Ларшин, Ю.Н. Кривошапка, С.А. Дитиненко, Г.А. Оборский, В.М. Тонконогий, П.Т. Слободяник. – Одесса, 2004. – 546 с.
3. Шевченко А.В. Повышение виброустойчивости токарной обработки на станке с потенциально неустойчивой упругой системой резец-суппорт // Вестник ГГТУ им. П.О. Сухого: научно-практический журнал. – Гомель, 2009. – Вып. 1. – С. 10-15.
4. Кудинов В.А. Динамические расчеты станков (основные положения) // СТИН. – 1995. – №8. – С. 3-13.

Стреляная Юлия Олеговна – кандидат технических наук, доцент кафедр «Начертательная геометрия, инженерная и компьютерная графика», Севастопольский государственный университет, Россия, г.Севастополь, joulia.bayrakova@mail.ru	Strelyanaya Yuliya Olegovna – candidate of technical sciences, associate professor of department «Descriptive geometry, engineering and computer graphics», Sevastopol State University, Sevastopol, Russia, joulia.bayrakova@mail.ru
--	---

Received 30.11.2019