DOI 10.52209/1609-1825_2021_3_29 UDC 534.1; 621.9

Mathematical Modeling of Dynamic Processes That Occur During Vortex Boring of Deep Holes with a Multi-Pass Cutter

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Abstract. *The purpose of the article is mathematical modeling and further research of the projected method of diagnostics of dynamic processes of vortex boring in order to determine the optimal processing mode. The design scheme of the technological system for vortex boring is given. The input parameters of the technological system for modeling cutting processes are determined. The values of the stiffness coefficients and damping coefficients for the technological system are determined. Systems of linear inhomogeneous differential equations for each element of the technological system are presented. Graphs of the dependence of the amplitude on time for displacement, velocity and acceleration are obtained. The spectrograms of displacement, velocity and acceleration are obtained separately for each node of the technological system, showing the dependence of the amplitude on the frequency.*

Keywords: *diagnostics, dynamic processes, vortex boring, displacement, speed, acceleration, lathe.*

Introduction

The study of dynamic processes is an urgent task of our time. The cutting process is a complex process that takes place at high speeds, temperatures and pressures acting on the cutter and, as a result, on the machine tool-device-tool-detail (MDTD) [1]. To date, vortex boring is performed with a single-pass cutter, but the use of multi-pass cutters will significantly improve the quality of processing the product due to the distribution of cutting forces among the cutting edges that are engaged, as well as increase productivity. However, the dynamics of vortex boring with the use of a multi-pass cutter head has not been fully studied, which is a big omission. The quality of material processing can be improved by using structural and technological methods [2]. The most cost-effective method is the technological method. Therefore, it is relevant to build a mathematical model of dynamic processes that occur during the vortex boring of deep holes with a multi-pass cutter.

Research methods

Since some components of the lathe affect the quality of workpiece processing, it was decided to reduce the schematic diagram shown in Figure 1 to 6 of the most important components of the lathe. From the point of view of dynamics, it is necessary to take into account the mass, stiffness coefficient and damping coefficient of each node of the system under study. The system consists of a cam, a turning chuck, a headstock, a bed, a caliper and tools (Figure 1).

According to the calculation scheme of the technological system (Figure 1), a system of differential equations is compiled, the solution of which was carried out by the fourth-order Runge-Kutta method [3]. Notation in the system of differential equations:

- $F(t)$ – disturbing force, (N);
- $Fm_n = m_n a_n$ – inertia force, (N);
- $Fc_n = c_n x_n$ – the reaction force of the support, (N);
- $Fh_n = h_n V_n$ – elastic force, (N);
- m_n – unit weight, (kg);
- a_n – acceleration, (mm/s^2);
- c_n – stiffness coefficient, (N/m);
- x_n – displacement, (mm);
- h_n – damping coefficient, (N·s/m);
- V_n – speed, (mm/s).

When modeling, the harmonic law of changing the disturbing force is adopted [3]:

$$F(t) = A * \sin(\omega * t). \qquad (1)$$

where A – the amplitude of the disturbing force is equal to the value of the eccentricity of the eccentric shaft, (mm);
ω – angular frequency (frequency), rad/s (Hz);
t – time, (s).

The assumption about the harmonic law of the action of the cutting force is accepted in this work from the consideration of identifying the reaction of the elements of the technological system to such an impact [4], as well as the fact that the signal form $F(t)$ during the spectral transformation will have a fundamental harmonic at the specified frequency ω [5].

Results and discussion

The system of linear inhomogeneous differential equations takes the following form:

An external force directly affects the chuck and the tool holder, which allows you to create equations:

$$F(t) = Fm_1 + Fc_1 + Fh_1, \qquad (2)$$

$$F(t) = m_1 a_1 + c_1(x_1 - x_2) + h_1(V_1 - V_2), \qquad (3)$$

$$F(t) = Fm_6 + Fc_6 + Fh_6, \qquad (4)$$

$$F(t) = m_6 a_6 + c_6(x_6 - x_5) + h_6(V_6 - V_5). \qquad (5)$$

From the tool holder, the force is transferred to the caliper, and from the workpiece to the cartridge:

$$Fc_6 + Fh_6 = Fm_5 + Fc_5 + Fh_5, \qquad (6)$$

$$\begin{aligned} &c_6(x_6 - x_5) + h_6(V_6 - V_5) = \\ &= m_5 a_5 + c_5(x_5 - x_4) + h_5(V_5 - V_4), \end{aligned} \qquad (7)$$

$$Fc_1 + Fh_1 = Fm_2 + Fc_2 + Fh_2, \qquad (8)$$

$$\begin{aligned} &c_1(x_1 - x_2) + h_1(V_1 - V_2) = \\ &= m_2 a_2 + c_2(x_2 - x_3) + h_2(V_2 - V_3). \end{aligned} \qquad (9)$$

The cartridge transfers the force to the front headstock:

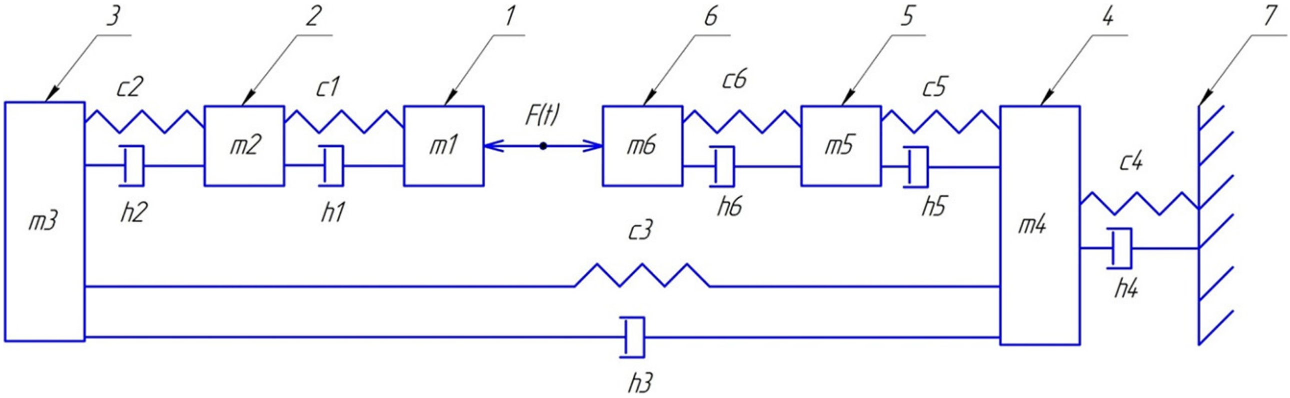
$$Fc_2 + Fh_2 = Fm_3 + Fc_3 + Fh_3, \qquad (10)$$

$$\begin{aligned} &c_2(x_2 - x_3) + h_2(V_2 - V_3) = \\ &= m_3 a_3 + c_3(x_3 - x_4) + h_3(V_3 - V_4). \end{aligned} \qquad (11)$$

The headstock and the caliper are mounted on the frame and transmit the total force to it:

$$Fc_3 + Fh_3 + Fc_5 + Fh_5 = Fm_4 + Fc_4 + Fh_4, \qquad (12)$$

$$\begin{aligned} &c_3(x_3 - x_4) + h_3(V_3 - V_4) + c_5(x_5 - x_4) + \\ &+ h_5(V_5 - V_4) = m_4 a_4 + c_4 x_4 + h_4 V_4. \end{aligned} \qquad (13)$$



1 – blank; 2 – turning chuck; 3 – headstock; 4 – bed; 5 – caliper; 6 – tools; 7 – cam

Figure 1 – Calculation scheme of the technological system

The values of the parameters of the mathematical model are entered into the MatLab software (Figure 2).

A system of linear inhomogeneous differential equations is written in MatLab (Figure 3).

According to the specified parameters, the

Table of values

Weight, kg	m_1	m_2	m_3	m_4	m_5	m_6
	5	20	150	620	60	8
Stiffness coefficient, 10^6 N/m	c_1	c_2	c_3	c_4	c_5	c_6
	100	80	90	300	15	35
Damping coefficient, N·s/m	h_1	h_2	h_3	h_4	h_5	h_6
	80	100	300	100	80	70

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```
A=0.005;% м
m1=5;% кг
m2=20;
m3=150;
m4=620;
m5=60;
m6=8;

h1=80; %
h2=100;
h3=300;
h4=100;
h5=80;
h6=70;

C1=80000000; % Н/м
C2=60000000;
C3=90000000;
C4=300000000;
C5=15000000;
C6=35000000;
```

Figure 2 – The values of the parameters of the mathematical model are entered into the MatLab software

```
% natural frequencies
f1=sqrt(C1/m1)/(2*pi)
f2=sqrt((C1+C2)/m2)/(2*pi)
f3=sqrt((C2+C3)/m3)/(2*pi)
f4=sqrt((C3+C4+C5)/m4)/(2*pi)
f5=sqrt((C5+C6)/m5)/(2*pi)
f6=sqrt((C6)/m6)/(2*pi)

f=10;% Gz
w=f*2*pi;% conversion to radians      % must be placed before the equation!
F=A*sin(w*t);

a1=(F-h1*(V1-V2)-C1*(x1-x2))/m1;
a2=(C1*(x1-x2)+h1*(V1-V2)-h2*(V2-V3)-C2*(x2-x3))/m2;
a3=(C2*(x2-x3)+h2*(V2-V3)-h3*(V3-V4)-C3*(x3-x4))/m3;
a4=(C3*(x3-x4)+h3*(V3-V4)+C5*(x5-x4)+h5*(V5-V4)-C4*x4-h4*V4)/m4;
a5=(C6*(x6-x5)+h6*(V6-V5)-h5*(V5-V4)-C5*(x5-x4))/m5;
a6=(F-C6*(x6-x5)+h6*(V6-V5))/m6;
```

Figure 3 – A system of linear inhomogeneous differential equations in MatLab

results of displacement, velocity and acceleration are obtained, shown in Figures 4-6.

We will construct spectrograms of displacement, velocity and acceleration separately for each node of the technological system (Figure 7-12).

From the data obtained, which are clearly presented in Figures 7-12, the efficiency of the mathematical model is observed, therefore, this mathematical model can allow comparative analyses of subsequent experiments by changing the input parameters.

Conclusions

As a result of the conducted research, a mathematical model of the vortex boring process is theoretically investigated using a multi-pass cutter head to identify the natural frequencies of the bearing elements based on the results of which it is possible to determine the optimal processing modes.

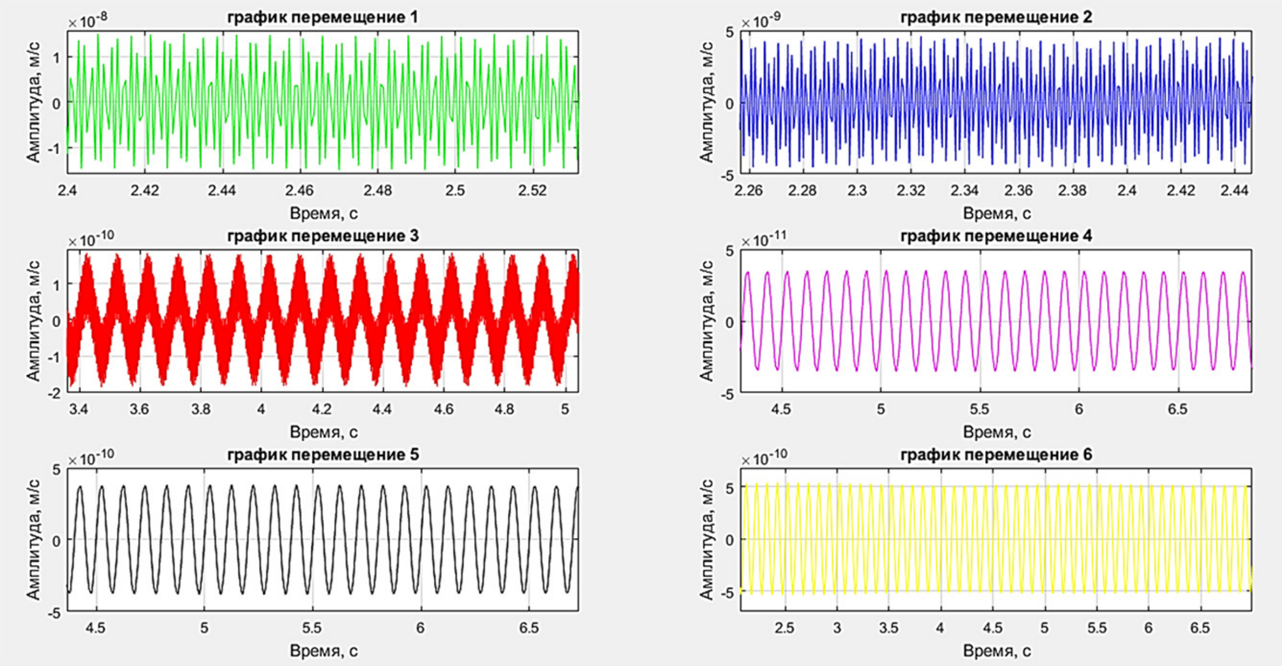

Figure 4 – Replacement

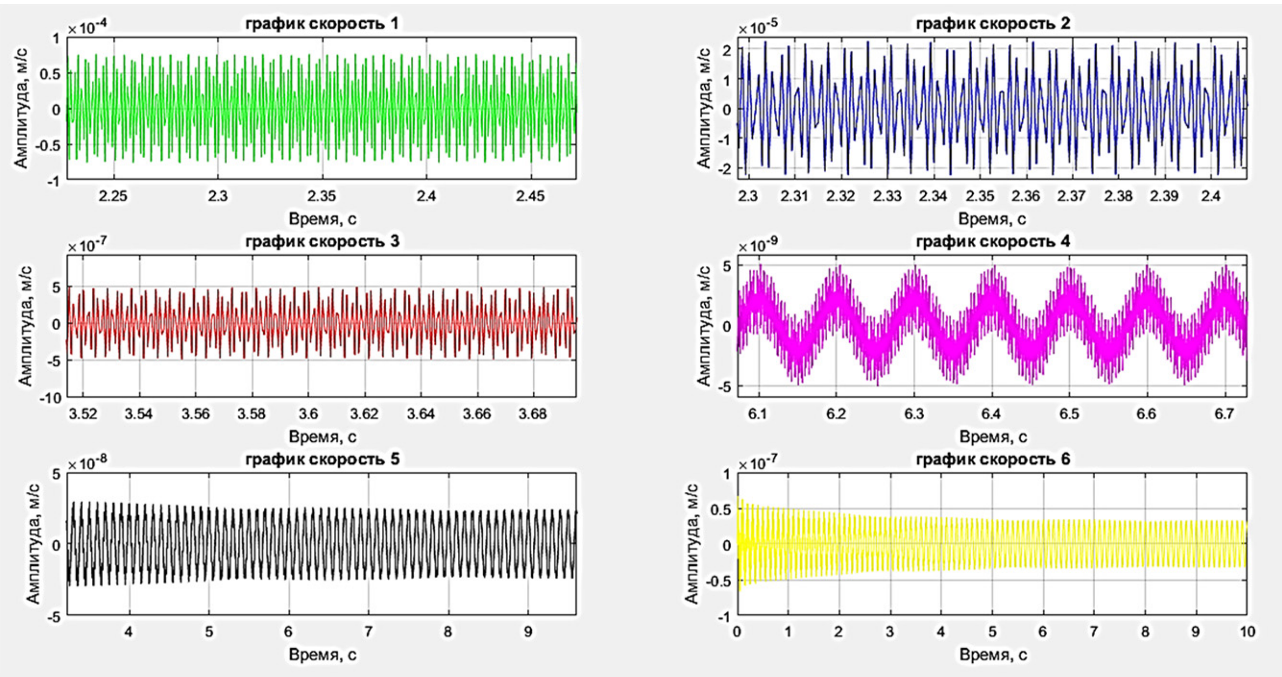

Figure 5 – Speed

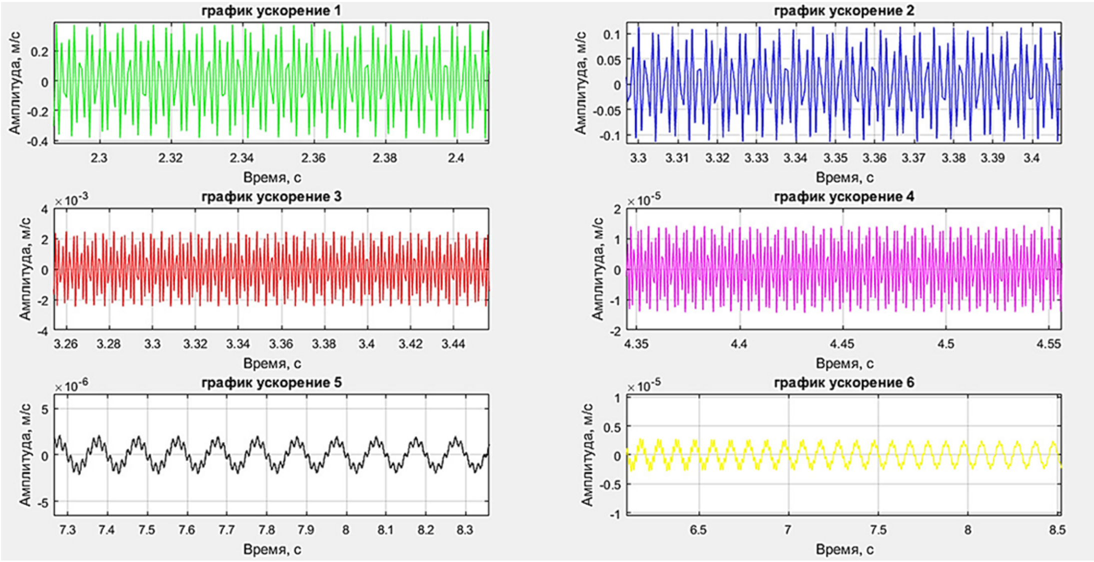

Figure 6 – Acceleration

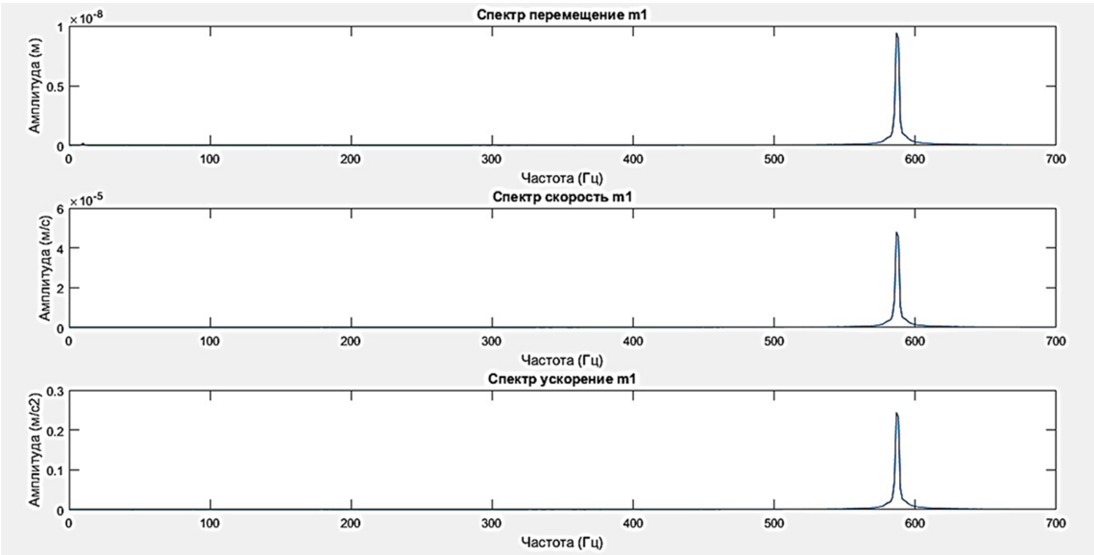

Figure 7 – Spectrograms of displacement, velocity and acceleration of the workpiece

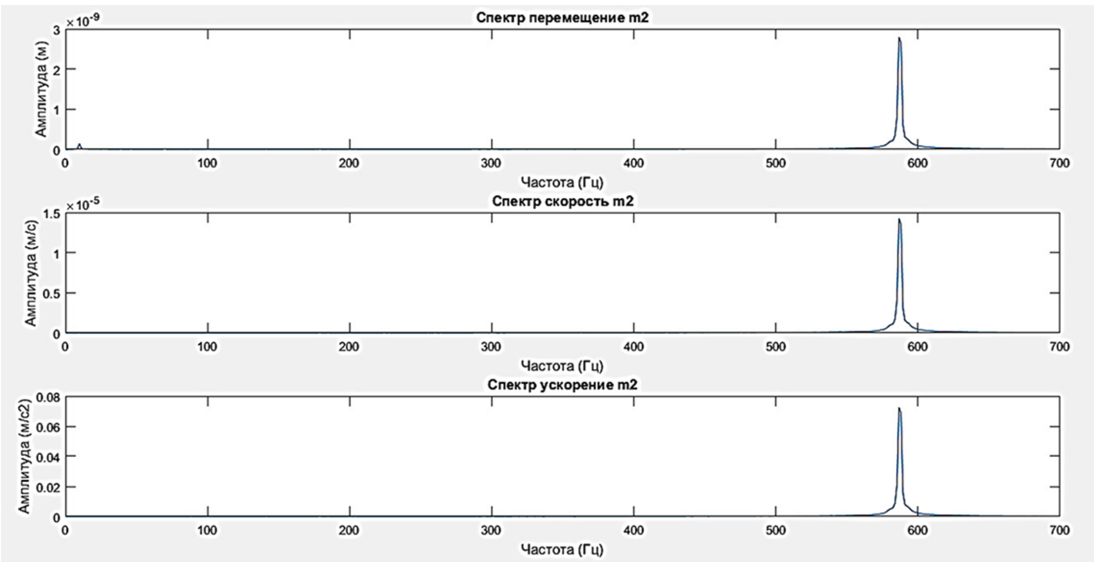

Figure 8 – Spectrograms of the movement, velocity and acceleration of the cartridge

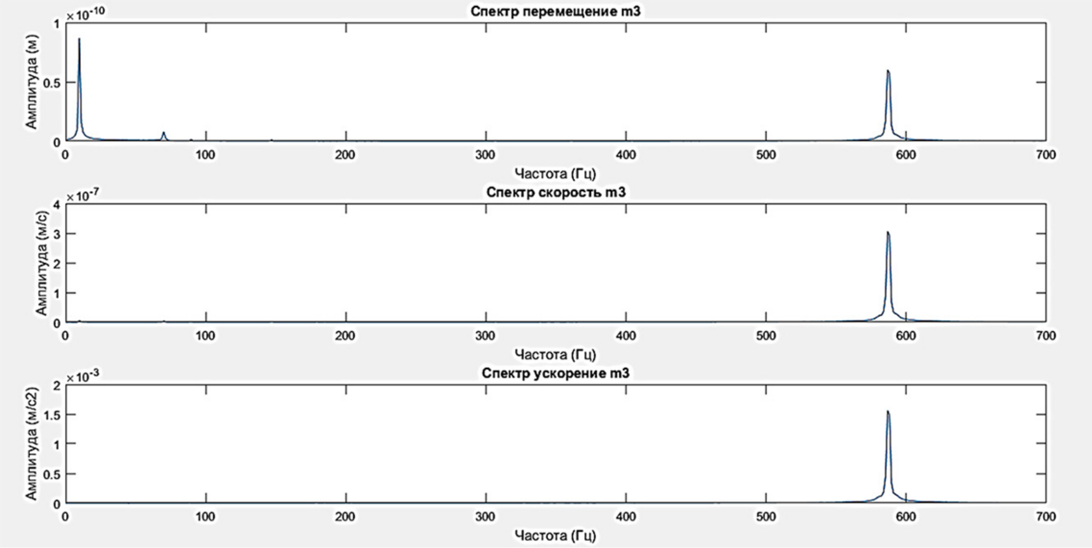

Figure 9 – Spectrograms of displacement, speed and acceleration of the headstock

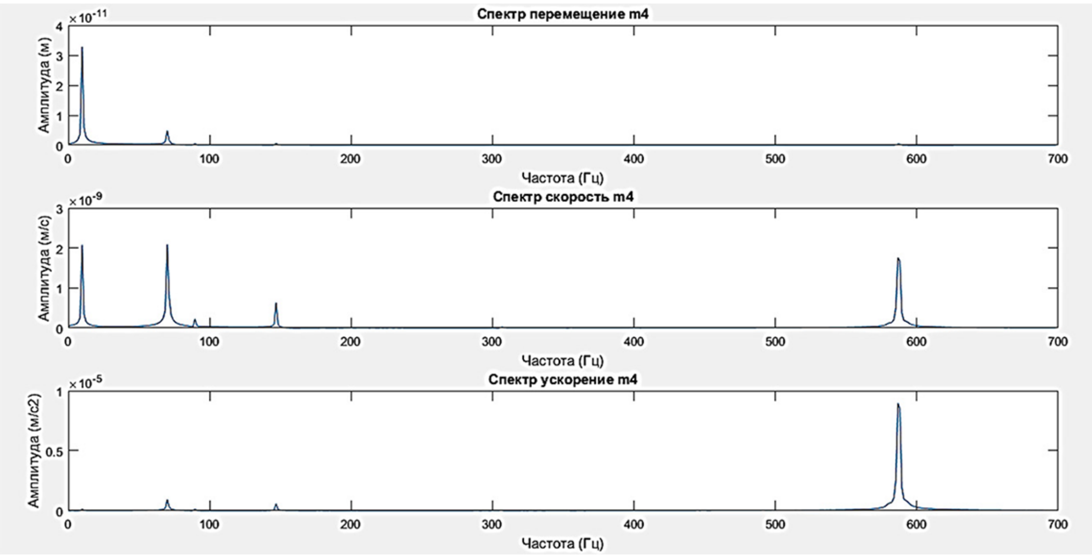

Figure 10 – Spectrograms of the replacement, speed and acceleration of the bed

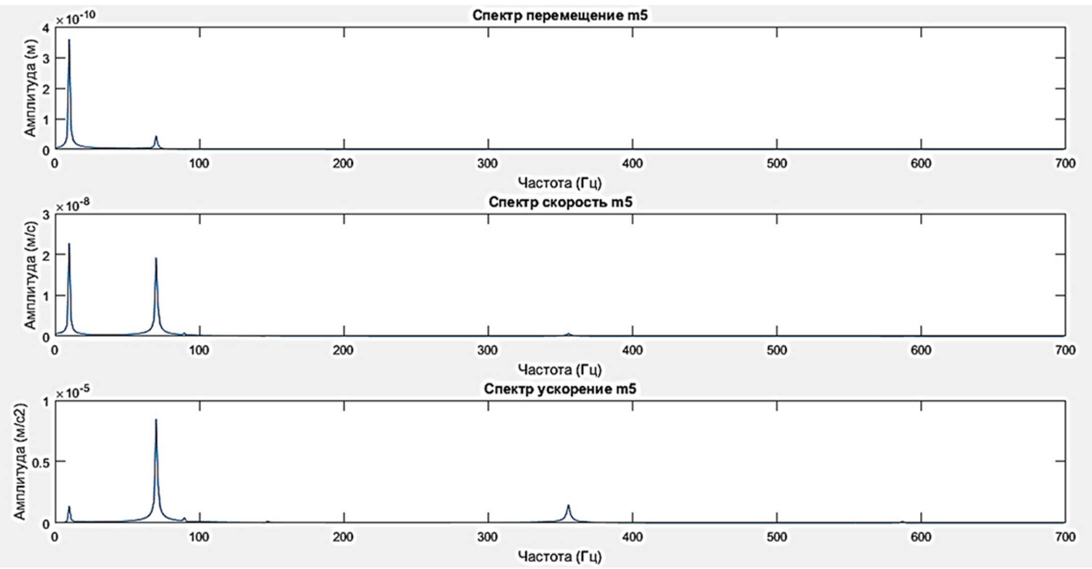

Figure 11 – Spectrograms of replacement, speed and acceleration of the caliper

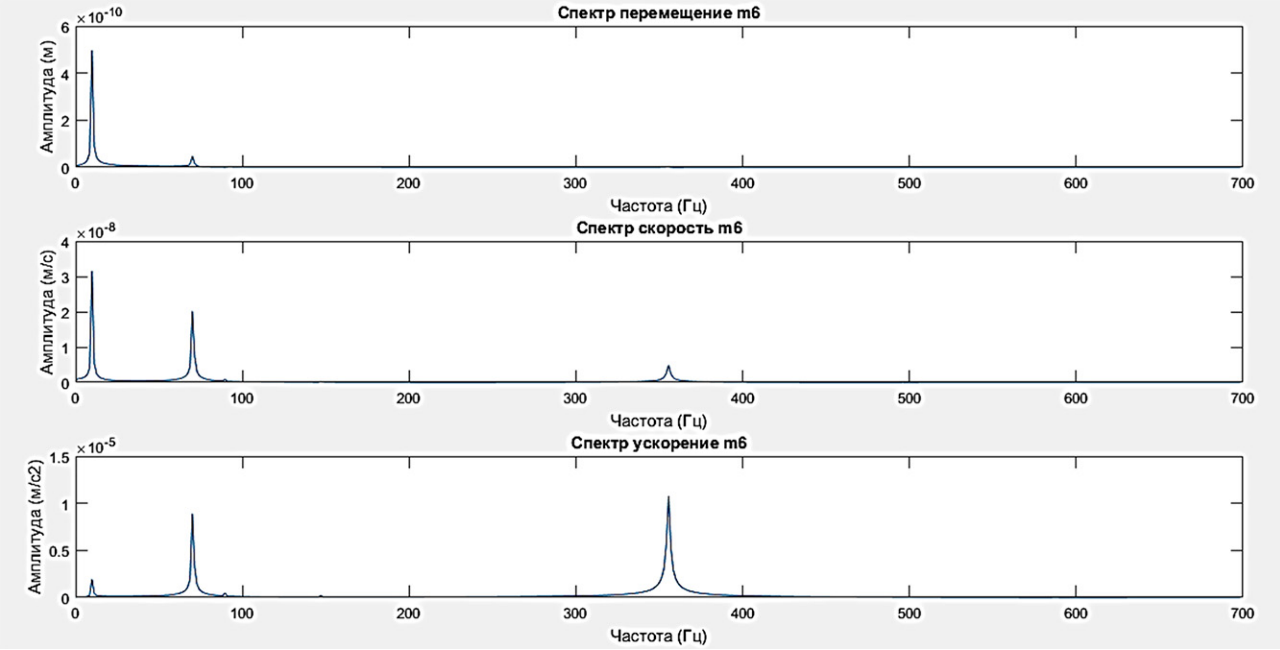

Figure 12 – Spectrograms of replacement, velocity and acceleration of the cam

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Вортекстің жұмыс өткіштегі кесікті түрі тесіктерді заңдату үшін динамикалық процестерді математикалық үлгілеу

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Аңдатпа. *Мақаланың мақсаты-өңдеудің оңтайлы режимін анықтау үшін құйынды бұрғылаудың динамикалық процестерін диагностикалаудың жобаланған әдісін математикалық модельдеу және одан әрі зерттеу. Құйынды бұрғылауға арналған технологиялық жүйенің жобалық схемасы келтірілген. Кесу процестерін модельдеуге арналған технологиялық жүйенің кіріс параметрлері анықталды. Технологиялық жүйе үшін қаттылық коэффициенттерінің және демпфирлеу коэффициенттерінің мәндері белгіленді. Технологиялық жүйенің әр элементі үшін сызықты гетерогенді дифференциалдық теңдеулер жүйесі келтірілген. Амплитуданың қозғалыс, жылдамдық және үдеу уақытына тәуелділік графиктері алынды. Амплитуданың жиілікке тәуелділігін көрсететін технологиялық жүйенің әр түйіні үшін қозғалыс, жылдамдық және үдеу спектрограммалары алынды.*

Кілт сөздер: *диагностика, динамикалық процестер, құйынды бұрғылау, қозғалу, жылдамдық, үдеу, токарьлық станок.*

Математическое моделирование динамических процессов, происходящих при вихревом растачивании глубоких отверстий многопроходным резцом

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Аннотация. *Целью статьи является математическое моделирование и дальнейшее исследование проектируемого метода диагностики динамических процессов вихревого растачивания с целью определения оптимального режима обработки. Приведена расчетная схема технологической системы для вихревого растачивания. Определены входные параметры технологической системы для моделирования процессов резания. Установлены значения коэффициентов жесткости и коэффициентов демпфирования для технологической системы. Приведены системы линейных неоднородных дифференциальных уравнений для каждого элемента технологической системы. Получены графики зависимости амплитуды от времени для перемещения, скорости и ускорения. Получены спектрограммы перемещения, скорости и ускорения отдельно для каждого узла технологической системы, показывающие зависимость амплитуды от частоты.*

Ключевые слова: *диагностика, динамические процессы, вихревое растачивание, перемещение, скорость, ускорение, токарный станок.*

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