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Determining the temperature field of circular saws

Bakirov Zh.B., Bakirov M. Zh., Mikhailov V.F.*
Karaganda State Technical University, Kazakhstan
*corresponding author

Abstract. The problem of determining the temperature field in circular saws with diamond segments along the outer contour is solved. The thermal conductivity equation for such disks is derived and boundary conditions are formulated. The specific heat flow and temperature field are represented as a Fourier series expansion along a circumferential coordinate. For each harmonic, the exact solution of the thermal conductivity equation is found in the form of a combination of modified Bessel functions. When solving the problem, the disk cooling method is taken into account. As a result of the solution and reasonable simplification, an axisymmetric temperature field is obtained, which changes exponentially along the radius of the disk. The results can be used to evaluate the stability of the flat shape of the balance of circular saws and the stability of diamond segments.

Keywords*:* circular saw, stone processing, thermal conductivity equation, temperature field, Nusselt criterion, Bessel functions.

1. Introduction

The increase in production of solid minerals, mineral raw materials and natural stone is associated with the technique and technology of effective and economical destruction of strong rocks. Analysis of existing methods of mass destruction shows that the solution to this problem often involves the creation and use of high-performance machines and mechanisms with disk actuators equipped with diamond segments, which are also used for sawing metal workpieces. During operation, circular saws are subjected to cutting and feeding forces, inertia forces, and temperature fields. All these loads act in the plane of the cutting disc and can cause a loss of stability of the disc saws.

A large amount of theoretical and experimental studies in the use of saws with diamond segments in the stone and mining industry performed in institutes ISI Almaz, CISI Podzemmash (Moscow), IAS of Ukraine (Kyiv), RISS (Yerevan), Institute of Nerud (Tolyatti), KarPTI, KNIUI (Karaganda) [1-3]. Similar studies were conducted in the United States, Germany, England, the Czech Republic, Slovakia and Poland. At the same time, issues related to the study of the influence of physical and mechanical properties of rocks and cutting modes on the energy and force indicators of destruction, wear and temperature conditions of the tool were considered. Despite a large amount of research, not enough attention is paid to determining the temperature field of disk saws. It was set in various ways, most often in the form of a power function over the radius, the coefficients of which were determined experimentally.

Most journal articles on this topic are devoted to determining the temperature field of brake discs [4-6]. The closest approach to this problem is the article [7], where the influence of the temperature field of a disk cutter on the destruction of rocks is studied. In these works, the finite element method [5-7] or the grid method [4] is used to solve heat conduction problems. In [8], an experimental-analytical method is proposed for determining the temperature field, when measured temperature values are initiated at individual points on the experimental setup, which are modelled using the green function. The thermal conductivity problem is solved by the method of integral transformations using the measured boundary values of the temperature field.

This article offers an analytical method for determining the temperature field in disk saws.

2. Methods and solution of basic relations

To derive the thermal conductivity equation, select an element with dimensions dr and $rd\theta$ from the disk. Then the amount of heat entering the element during dt can be determined by the formula [4]

$$Q_1 = h\lambda\nabla^2 Tr\, dr\, d\theta\, dt,$$

where h is a plate thickness;

λ is a thermal conductivity;

$\nabla^2 = \frac{\partial^2}{r^2\,\partial\,\theta^2} + \frac{\partial}{r\,\partial r} + \frac{\partial^2}{\partial r^2}$ is a harmonic operator in polar coordinates.

Heat transfer from the surface of the element due to convective heat exchange is equal to

$$Q_2 = 2\alpha(T - T_c) r dr d\theta dt,$$

where T_c is an ambient temperature;

α is an average heat transfer coefficient.

By rotating the disk, the selected element moves along the circumferential coordinate. During dt its temperature changes by a value of:

$$dT = \frac{\partial T}{\partial \theta} \cdot \frac{\partial \theta}{\partial t} \partial t = \frac{\partial T}{\partial \theta} \omega dt,$$

where ω is an angular speed of disk rotation.

In this case, the amount of heat changes by a value of:

$$Q_3 = C\rho h\, dr\, dt\, dT d\theta,$$

where C, ρ are specific heat capacity and density of the material.

The heat balance equation has the form:

$$Q_1 = Q_2 + Q_3.$$

Dividing both parts of the equation by $r \cdot drd\theta dt$ we get:

$$h\lambda \nabla^2 T = 2\alpha(T - T_c) + C\rho h\omega\, \partial T/\, \partial \theta.$$

Moving to the dimensionless radius $x = r/R$ we have:

$$\nabla^2 T - m^2 T - p\frac{\partial T}{\partial \theta} = 0, \tag{1}$$

where T is the disk temperature exceeds the ambient temperature;

$m^2 = 2\alpha R^2/h\lambda$ is a Bio criterion;

$p = VR/a$ is a Peclet criterion;

$a = \lambda/C\rho$ is a thermal diffusivity of the material;

V is a circumferential speed on the outer contour of the disk of radius R.

The circular saw consists of a steel body and an annular abrasive layer with an outer radius of R_H. Then the boundary conditions for the thermal conductivity equation have the form:

$$\lambda_c\, \partial T_1/R\, \partial x + \alpha_H T_1 = q, \quad \text{if } x = \beta_H = R_H/R;$$
$$\lambda_c\, \partial T_1/\, \partial x = \lambda\, \partial T/\, \partial x\,, \quad T_1 = T \text{ if } x = 1; \frac{\partial T}{\partial x} = 0 \quad \text{if } x = \beta, \tag{2}$$

where q is a specific heat flow;

λ_c is a coefficient of thermal conductivity of segments;

β is a dimensionless internal radius of the disk.

In the boundary conditions (2), heat transfer with the coefficient α_H from the cylindrical surface of the abrasive layer is taken into account. 1st index refer to the abrasive layer.

The average heat transfer coefficient is calculated using the Nusselt criterion [3]

$$\alpha = N_u \lambda_{cp}/R, \tag{3}$$

where λ_{cp} is a thermal conductivity of the environment.

When cooling circular saws by air flow, the N_u criterion can be determined by the formula

$$N_u = 0.015 R_e^{0.8} - 100(\rho_{max}/R)^2, \tag{4}$$

where $R_e = VR/\nu_a$ is a Reynolds criterion;

ν_a is a kinematic air viscosity;

$\rho_{max} = 500(\nu_a/\omega)^{1/2}$ is the maximum radius of the laminar air flow zone.

When cooling with a liquid, it can be assumed that a turbulent flow occurs at [9]

$$R_\mathrm{e} = V_0 R/\nu_0 \geq 5 \cdot 10^5.$$

The Nusselt criterion is calculated using the formulas [3, 9]: for laminar flow

$$N_u = 0.8\sqrt{R_e}\,; \tag{5}$$

for turbulent flow $N_u = 0.043 R_e^{0.8}$.

The specific heat flow on the outer contour of the abrasive layer is decomposed into a Fourier series:

$$q = q_0 \sum_{n=0}^{\infty} (\ell_n \cos n\theta + g_n \sin n\theta) = q_0 \sum_{n=-\infty}^{\infty} C_n \exp(in\theta),$$

where q_0 is a characteristic value of heat flow.

The specific heat flow can be found from the ratio

$$Q = \int_S q dS,$$

where S is the surface area of the heat flow;

Q is the amount of heat entering the disk per unit of time.

The value Q can be determined by the formula

$$Q = 3600 N_p K_d / j \quad \text{(kcal/h)},$$

where N_p is the cutting power, kW;

K_d is a coefficient that takes into account the proportion of heat entering the disk;

j=4.187 is the thermal equivalent of mechanical energy.

Based on the representation of the heat flow and boundary conditions (2), we look for a solution (1) in the form

$$T = \sum_{n=-\infty}^{\infty} T_n \exp(in\theta).$$

Then equation (1) for each term of the decomposition takes the form:

$$\left[\frac{d^2}{dx^2} + \frac{d}{xdx} - \left(m^2 + inp + \frac{n^2}{x^2}\right) T_n\right] = 0.$$

The solution to this equation has the form

$$T_n = A_n I_n(kx) + B_n K_n(kx) \tag{6}$$

where I_n, K_n are modified Bessel functions of 1st and 2nd types;

$k = (m^2 + inp)^{1/2}$.

The boundary conditions (2) can now be represented as

$$\begin{gathered} x = \beta_H: \quad dT_{n_1}/dx + nT_{n_1} = \bar{q} C_n; \\ x = 1: \quad \lambda\, dT_{n_1}/dx = \lambda dT_n/dx, T_{n_1} = T_n; \\ x = \beta: \quad dT_n/dx = 0, \end{gathered} \tag{7}$$

where $\bar{q} = q_0 R/\lambda_c$,

$n_H = \alpha_H R/\lambda_c$.

Substituting (6) in (7), we define constant integrations for the saw body, which are calculated using the following algorithm:

$$\begin{gathered} C_p = K_n(k_1)[k_1 I'_n(\beta_{\text{н}} k_1) + n_{\text{н}} I_n(\beta_{\text{н}} k_1)] - I_n(k_1)[k_1 K'_n(\beta_{\text{н}} k_1) + n_{\text{н}} K_n(\beta_{\text{н}} k_1)]; \\ A_p = D_p I_n(k) - \frac{k\lambda}{k_1 \lambda_c} C_p I'_n(k) - \frac{I'_n(\beta k)}{K'_n(\beta k)} \left[D_p K_n(k) - \frac{k\lambda}{k_1\lambda_c} C_p K'_n(k)\right]; \\ A_n = -\frac{\bar{q} C_n}{k_1 A_p}; B_n = \frac{\bar{q} C_n}{k_1 A_p} \cdot \frac{I'_n(\beta k)}{K'_n(\beta k)}. \end{gathered}$$

The A_p coefficient is determined from the expression for C_p by replacing $K_n(k_1)$, $I_n(k_1)$ with $K_n'(k_1)$, $I_n'(k_1)$, respectively. To simplify the obtained relations, we note that usually $\beta_H = 1{,}017 \ldots 1{,}02$, $\beta = 0{,}1 \ldots 0{,}3$;

$$k = (m^2 + inp)^{1/2} = [(\sqrt{n^2p^2 + m^4} + m^2)^{1/2} + i(\sqrt{n^2p^2 + m^4} - m^2)^{1/2}]/\sqrt{2}.$$

Since m^2 and m_c^2 are of order $10^2 \ldots 10^4$, p and p_1 are of order $10^5 \ldots 10^7$, then $np \gg m^2$, so $k \approx \lambda_n(1 + i)$, where $\lambda_n = (np/2)^{1/2}$.

It follows that the Bessel functions when defining integration constants can be decomposed into a series for large argument values. Then, neglecting the higher-order terms of smallness, we get

$$T_n = -\frac{\bar{q}C_{\text{n}} \exp\big(-k(1-x)\big)}{k_1\sqrt{x}\left(D_p - C_{\text{p}}\frac{k\lambda}{k_1\lambda_c}\right)}. \tag{8}$$

To obtain a valid expression for the temperature field, we write it in the form of trigonometric Fourier series

$$T = T_0 + \sum_{n=1}^{\infty}(T_{cn}\cos n\theta + T_{sn}\sin n\theta\,), \tag{9}$$

where $T_{cn} = T_n + T_{-n}$, $T_{sn} = i(T_n - T_{-n})$, $T_{-n} = -\bar{q}\frac{C_{-n}\exp(-k(1-x))}{\bar{k}_1\sqrt{x}\left(\bar{D}_p - {}^{\bar{C}_p\lambda\bar{k}}/_{\lambda_c\bar{k}_1}\right)}$.

In the last expression, symbols with a dash on top mean complex-conjugate numbers. After a sequence of mathematical transformations, we get

$$T_{sn} = \frac{2\bar{q}\sqrt{2\beta_H}\exp(-\gamma_n)}{\sqrt{np_1x}}(K\cdot\cos\gamma_n - L\cdot\sin\gamma_n), \tag{10}$$

where $K = [(1 + n_H/\lambda_{n1})l_n - g_n]/E$;

$L = [l_n + (1 + n_H/\lambda_{n1})g_n]/E$;

$E = (1 + \sqrt{a_c/a}\cdot\lambda h/\lambda_c b_c)[1 + (1 + n_H/\lambda_{n1})^2]$;

$\gamma_n = \lambda_n(1-x) + \chi_n$;

$\chi_n = \lambda_{n1}(\beta_H - 1)$;

l_n, g_n are the coefficients of decomposition of the specific heat flow into the Fourier trigonometric series.

The component T_{sn} is defined by the expression (10) replacing K by L and L by $(-K)$.

The axisymmetric component of the temperature field T_0 is found from (10), assuming $C_n = l_0$, $k_1 = m_c$, $k = m$, $C_p = [\text{ch}\chi_0 + (n_H/m_1)\text{sh}\chi_0]/\sqrt{\beta_H}$, where $\chi_0 = m_c(\beta_H - 1)$.

The coefficient D_0 is defined by the same expression by replacing ch with (−sh) and sh with (−ch). After elementary transformations we get

$$T_0 = \bar{q}l_0\sqrt{\beta_H/x}\exp[-m(1-x)]/m_cD_0, \tag{11}$$

where $D_0 = \left(n_H/m_c + {}^{m\lambda}/_{m_c\lambda_c}\right)\text{ch}\chi_0 + \left(1 + {}^{m\lambda n_H}/_{m_c^2\lambda_c}\right)\text{sh}\chi_0$.

The change in the temperature field is estimated by the circumferential coordinate on the outer contour of the saw body. In this case, expression (10) can be rewritten as

$$T = \frac{\bar{q}l_0\sqrt{\beta_H}}{m_cD_0}\left\{1 + \sum_{n=1}^{\infty}\frac{\sqrt{8}m_cD_0}{\sqrt{np_1}\exp(\chi_n)}[K\cos(n\theta - \chi_0) + L\sin(n\theta - \chi_0)]/l_0\right\}.$$

Analysis of this expression shows that under the sign of the sum is an exponentially decreasing series, each member of which is negligible in comparison with the unit at significant rotation speeds. Therefore for disk saws, the temperature field can be considered axisymmetric and changing along the radius of the disk according to the law

$$T = T_H\exp[-m(1-x)]/\sqrt{x}. \tag{12}$$

The temperature of the outer contour of the cutting disc body, taking into account the decrease in temperature due to the presence of intersegment slots, can be written as:

$$T_H = \bar{q}\sqrt{\beta_H}C_c/m_cD_0, \tag{13}$$

where C_c is the coefficient of discontinuity of the outer surface of the disk due to intersegment grooves.

For an axisymmetric temperature field, you can easily find the temperature in the cutting zone. To do this, in expressions (7), replace T_0 with the expression (11)

$$\left.\begin{aligned} A_0 I'_0(m_c x) + B_0 K'_0(m_c x) = (\bar{q}/m_c D_0)\sqrt{2\pi m \beta_H}\exp(-m) I'_0(mx) \\ A_0 I_0(m_c x) + B_0 K_0(m_c x) = (\bar{q}/m_c D_0)\sqrt{2\pi m \beta_H}\exp(-m) I_0(mx) \end{aligned}\right\} x = 1.$$

From here, after simplification and transformation, we get

$$A_0 = \bar{q}\sqrt{2\pi\beta_H/m_c}\exp(-m_c)/D_0,\ B_0 = \bar{q}\sqrt{\beta_H/2\pi m_c}\exp(m_c)/2mD_0.$$

Substituting them in (6), assuming $x = \beta_H$, we get the temperature in the cutting zone

$$T_p = \bar{q}\exp(\chi_0)[1 + \exp(-2\chi_0)/4m]/m_c D_0. \tag{14}$$

With sufficient cooling, the second term in parentheses can be ignored.

3. Results and discussion

To perform specific calculations, you need to know the coefficient of heat transfer to the disk. It depends on the thermal properties of the rock and segment, on the cutting modes, on the granularity and concentration of diamonds in the segment. The formula for determining the coefficient of heat transfer to the product during grinding has the form [2]:

$$\alpha_m = \left[1.25\frac{\lambda_c}{\lambda_m}\sqrt{\frac{a_m}{h_{cp}V}} + 1\right]^{-1}, \tag{15}$$

where a_m is the thermal diffusivity of the product;

λ_c, λ_m is a thermal conductivity of the segment and product;

h_{cp} is the average chip thickness cut by a diamond grain, determined by the formula [1].

$$h_{cp} = 0.8 r_a \lambda_p(\varphi_k - 0.16\sin 2\varphi_k - 0.012\sin 4\varphi_k)/\varphi_k,$$

where r_a is a radius of the diamond grains;

λ_p is a coefficient of cutting modes;

φ_k is an angle of contact of the disk with the product.

The coefficient of cutting modes is determined by the formula

$$\lambda = 14.5\left(\frac{V_n}{VC_c K_0}\right)^{\frac{1}{2}},$$

where V_n is a feed rate;

K_0 is a volume concentration of diamond in segments as a percentage.

The coefficient of heat transfer to the disk is now equal to $K_d = 1 - \alpha_m$.

As follows from the formula (12), the temperature field of the disk is determined by two parameters: m and T_n. When the design parameters of the saw and the thermal properties of the materials (disk, segment, product) are known, the temperature of the outer contour of the disk and the temperature in the cutting zone can be expressed in terms of a specific heat flow. Here is the procedure for calculating these parameters:

- depending on the properties of the cooling medium, we use the formula (3) to determine the average heat transfer coefficient;
- defining the Bio criteria for the disk and for segments (m and m_c);
- determine the coefficients n_H, χ_0 and using the formula (11) determine the coefficient D_0;
- using the formula (13), we determine the temperature of the outer contour of the disk through the specific heat flow;
- using the formula (14), we determine the temperature in the cutting zone.

Figure 1 shows a graph of the dependence of the temperature field parameters on the speed of the coolant when cutting granite. These values are accepted for calculations:

λ =38.5 kcal/m h °C, λ_c=72 kcal/m h°C;

for granite [10]:

λ_m = 3,5 kcal/m h°C, C_m = 0,74 kcal/kg ºC, ρ_m = 2720 kg /m^3;

for an aqueous solution [9]:

λ_o=0,52 kcal/m h°C, η=10 kg/m s, $\nu_o = \eta/\rho = 10^{-6}$ m^2 /s. , $R_e = 4\cdot 10^5$;

for the saw: R=0,4 m, h=4 mm, β_H=1,015.

The sharp increase in the Bio criterion at V_0 =1,25 m/s is explained by the transition of the flow from laminar to turbulent.

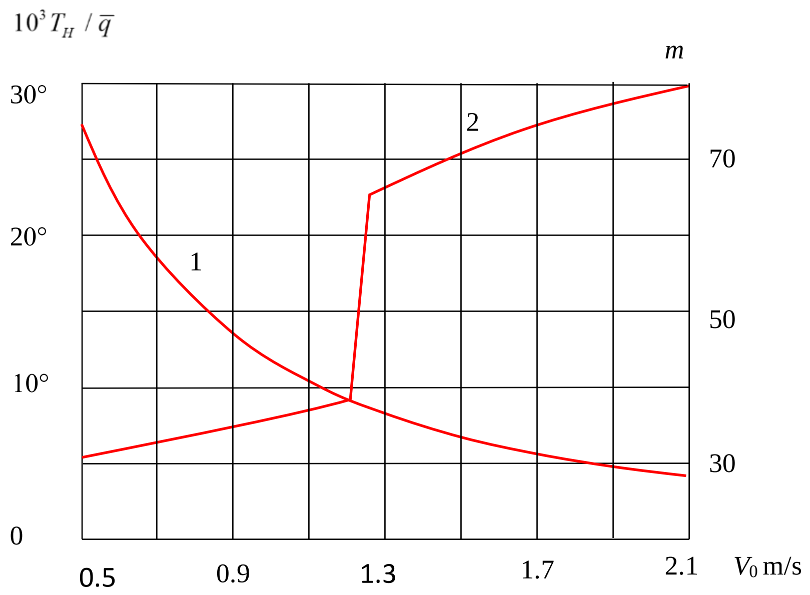

Fig. 1. - Graph of the dependence of the temperature field parameters of the cutting disc on the speed of the coolant: curve 1 is the relative temperature $T_H/\bar{q}$; curve 2 is the Bio criterion m

When specific cutting modes and power are known, the temperatures in the circular saw can be determined explicitly. To do this, the heat transfer coefficient to the product and then to the disk is determined using the formula (15). Next is the specific heat flow

$$\bar{q} = \frac{3600 K_d N_p}{2\pi j b_c \lambda_c \beta_H}.$$

To verify the results obtained, calculations were performed to determine the temperature field in saw disks by the finite element method using the ANSYS program [11]. Qualitative comparison of the results indicates that the obtained ratios are acceptable for practical calculations.

4. Conclusions

Based on the results of the research work, the following conclusions can be drawn:

- the dependence of the temperature field parameters in disk saws on the cutting modes and thermal properties of materials: disk, segment, product and coolant is obtained;
- it is found that for fast-rotating disks, the temperature field is axisymmetric and exponentially changing in radius.

The results obtained allow us to:

- investigate the thermal stability of circular saws;
- find a critical combination of operating parameters (cutting force, rotation speed, temperature field) from the stability condition of the plane form of equilibrium;
- adjust the temperature in the cutting area from the tool life condition by selecting the coolant parameters.

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Information of the authors

Bakirov Zhetpisbay Bakirovich, doctor of technical sciences, professor of the department "Mechanics" of Karaganda Technical University
E-mail: zh.bakirov@kstu.kz

Bakirov Madi Zhetpisbayevich, candidate of technical sciences, associate professor of the department "Mechanics" of Karaganda Technical University
E-mail: madybacirov@rambler.ru

Mikhailov Valentin Feliksovich, candidate of technical sciences, associate professor of the department “Mechanics” of Karaganda Technical University
E-mail: v.mihaylov@kstu.kz

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Simulation of the device for cleaning road surfaces from ice

Kozyrev A.N.*
Tomsk Polytechnic University, Tomsk, Russia
*corresponding author

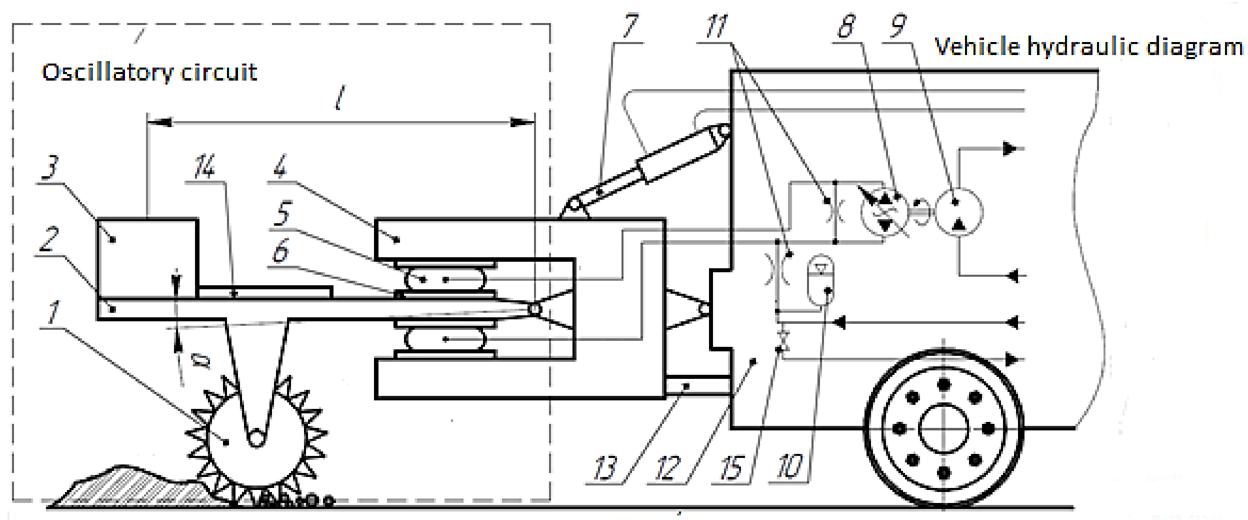
Abstract: The article discusses the design of a device for cleaning road surfaces from ice. The kinematic and hydraulic diagram of an experimental laboratory stand that simulates the operation of a device for cleaning road surfaces from ice is presented. The approbation of the mathematical model in the resonance mode has been carried out. The dependences of the displacements, the speed of the oscillating circuit on time in the resonant mode are obtained. The dependence of the amplitude and frequency of the oscillatory circuit is obtained.

Key words: stand, resonance mode, vibrations, sensor, movement, speed, vibrator, frequency, amplitude.

1. Introduction

Snow and ice that cover roads in winter, impede the movement of vehicles, are one of the main causes of road accidents and often lead to traffic jams when impressive traffic jams form on city streets and highways [1, 2]. To eliminate this problem, devices are used for cleaning road surfaces from ice, mechanical cleaning of the road from ice. [3].

The design of the device for cleaning road surfaces from ice is shown in Figure 1. The device is designed to ensure the safe movement of vehicles and pedestrians by increasing the coefficient of adhesion of tires to the road surface, ie. by changing the roughness of the road surface by means of mechanical cleaning [4].



1 - shear wheel; 2 - movable beam; 3 - cargo; 4 - frame; 5 - high pressure hoses; 6 - gaskets; 7 - stock; 8 - oscillator; 9 - hydraulic motor; 10 - hydraulic accumulator; 11 - jets; 12 - vehicle; 13 - retainer; 14 - a mechanism for adjusting the length of the arm; 15 - tap

Fig. 1. - Schematic diagram of a device for cleaning road surfaces from ice

The device has a main frame 4, pivotally connected to the vehicle 12, contains a latch 13. A beam 2 is connected to the main frame 4 by means of a hinge, on which a mechanism for adjusting the length of the load arm 3 is installed 3. The beam 2 is connected to the shear wheel 1 by means of sliding bearings. Shear wheel 1, movable beam 2 with load 3 and control mechanism 14 make up an oscillatory circuit (CC), which is pivotally connected to the main frame 4 [5].

The shear wheel 1 is a disc with teeth on its outer circumference. Spacers 6 and high-pressure hoses 5 are installed between the main frame 4 and the beam 2.

The device is driven from the hydraulic system of the vehicle using additional built-in hydraulic units: hydraulic pump, hydraulic motor 9, powered by the hydraulic system of the vehicle; an adjustable oscillator 8 connected by a hydraulic line to the high-pressure hoses 5. The elastic shells 5 of the high-pressure hoses between the stationary main frame of the device 4 and the movable beam 2 form a hydraulic vibrator (hereinafter referred to as a vibrator).

2. Results and discussion

In order to simulate the operation of a device for cleaning road surfaces from ice and conduct an experiment, the laboratory bench was modernized (Figure 2).

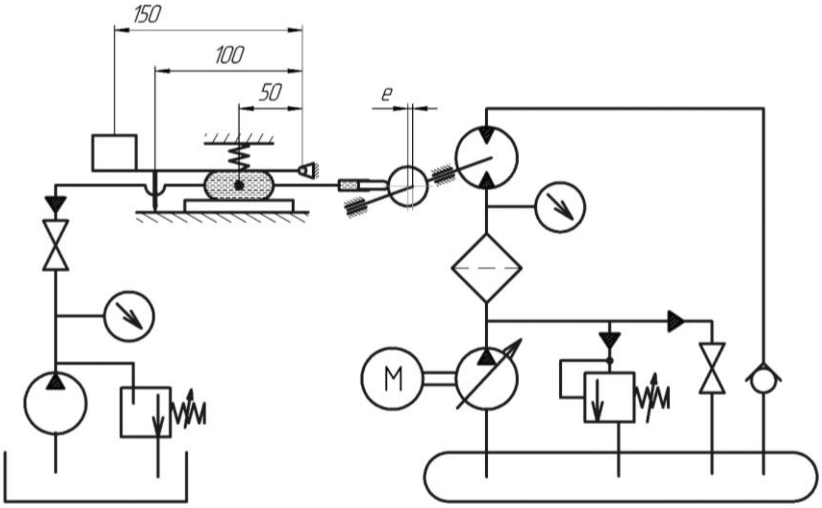


Fig.2. - Kinematic and hydraulic diagram of the experimental laboratory stand

The laboratory bench consists of an electric motor, which is connected through an elastic coupling to an adjustable volumetric hydraulic pump powered by hoses with a hydraulic tank. The pressure connection of the hydraulic pump is connected to a tee, which has a direct branch to the filter and a return branch to the safety valve and drain valve, which are connected to the hydraulic tank by means of metal pipes.

The filter is connected through metal pipes to the pressure gauge and the inlet of the hydraulic motor. The outlet of the hydraulic motor is connected to a check valve, which is installed in front of the hydraulic tank and transfers the fluid flow in one direction to the hydraulic tank. The hydraulic motor is connected through a clutch to an oscillator, which has a rolling bearing acting as an eccentric cam. The cam is in contact with the plunger pair, which is installed in the oscillator. The plunger pair is connected by means of metal tubes to one end of the high-pressure hose, which is radially deformed in the radial direction under the action of a cantilever beam with a movable weight. The cantilever beam is installed in a support by means of a sliding bearing, which is fastened by means of a threaded connection to a cylindrical platform (blank) that simulates a vehicle. The load of the movable beam is provided by a spring, which is attached to the fixed support with the upper end, and the lower end presses the high-pressure hose [6].

The second end of the high-pressure hose is connected through metal pipes with a drain cock, which is connected to a hand pump, a safety valve and a pressure gauge. The hand pump and safety valve are powered by an open tank.

The general view of the experimental laboratory stand is illustrated in Figures 3 and 4.

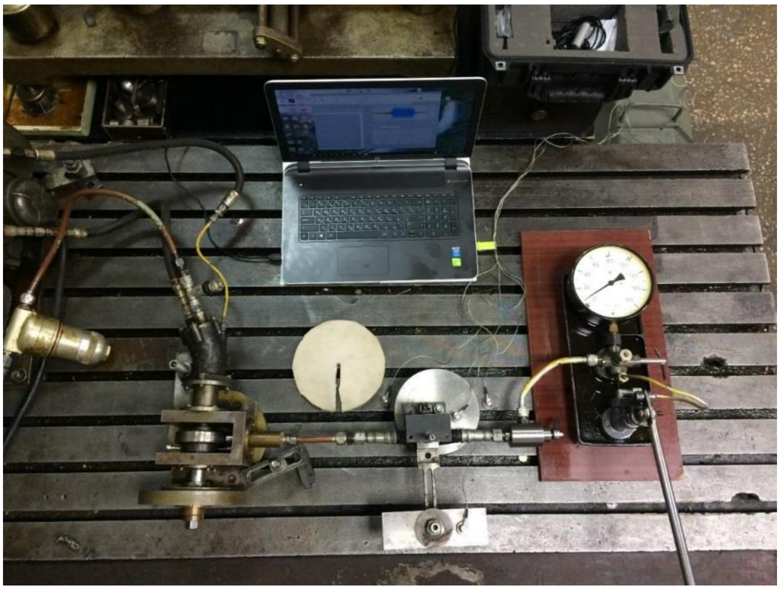


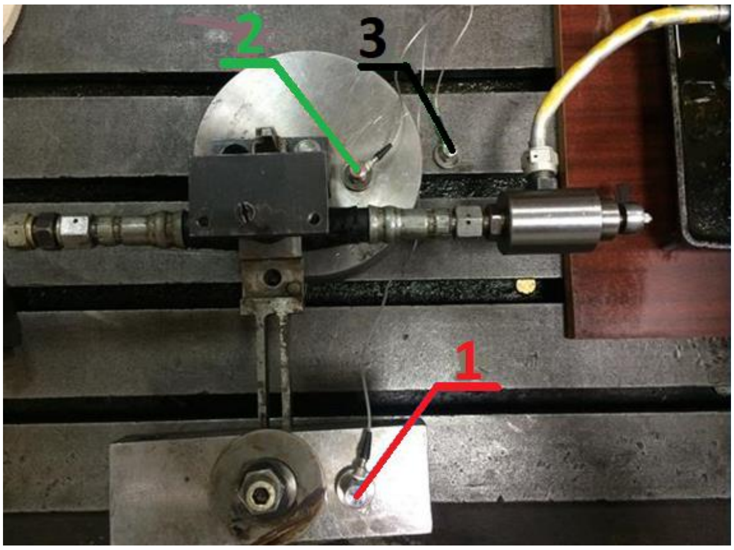
Fig.3. - General view of the experimental laboratory stand

Fig. 4. - General view of the experimental laboratory stand

2.1 Performing an experiment

An experiment was carried out on a laboratory bench to study the operation of the device in a resonant mode. The resonant mode was selected based on the calculated values of the parameters obtained by mathematical modeling, then the correction was made according to the measurement results.

Data measurements on the laboratory bench were carried out using a portable measuring complex K-5101, which were recorded in a laptop. For recording on a laptop, we used special software "Vibroregistrator-F" [7]. The sensors (accelerometers) were located as follows (Figure 5).



1 - on a movable platform that simulates an oscillatory circuit; 2 - on a mass that simulates a vehicle; 3 - on the base, imitating the road surface

Fig.5. - Installation diagram of sensors

Due to the fact that the laboratory stand is limited in technical characteristics in comparison with the mathematical model on which theoretical experiments were carried out (the stand does not allow reaching the movement of the oscillatory circuit equal to 130 mm), it was decided empirically to select the resonance mode (XX) of oscillations of the oscillatory circuit. Then, empirically measure all the coefficients at the stand and substitute them into the mathematical model to compare the results.

2.2 Preparing an experiment for testing a mathematical model

As a result of the experiment on the laboratory bench, the parameters of the mathematical model were adjusted.

The initial data of the theoretical study of the mathematical model are the parameters obtained in the work by calculation (table 1).

The initial data (Table 1) are presented taking into account the fact that the mathematical model is tested at XX, therefore, there is no load on the shear wheel ($c_1 = h_1 = 0$).

Table 1 - Initial parameters of the mathematical model

Parameter	Numerical value	Units
m_1	515	kg
m_2	20827	kg
c_1	0	N/m
c_2	10000000	N/m
c_3	1200000	N/m
h_1	0	N*s/m^2
h_2	273819	N*s/m^2
h_3	3480	N*s/m^2
l_1, l_2, l	0,05; 0,1; 0,15	m

The laboratory stand has its own parameters, some of them differ from the mathematical model of the device (Table 2).

Table 2 - Parameters of the laboratory stand

Parameter	Numerical value	Units
m_1	2,5	kg
m_2	25	kg
c_1	0	N/m
c_2	12000	N/m
c_3	5900	N/m
h_1	0	N*s/m2
h_2	2400	N*s/m2
h_3	400	N*s/m2
l_1, l_2, l	0,3; 0,8; 1	m

Taking into account a real experiment in the mathematical model, it is necessary to correct the following parameters:

- the reduced mass of the oscillating circuit and the vehicle;
- coefficients of stiffness of the high pressure hose and the vehicle;
- damping coefficients of the high-pressure hose and the vehicle;
- the length of the lever arms.

For approbation, it is necessary to substitute the corrected parameters that the laboratory stand possesses into the mathematical model.

Measurements of a real experiment during the operation of the laboratory stand at the XX in the resonance mode were carried out using a portable measuring complex K-5101, which were recorded in a laptop. For recording on a laptop, special software "Vibroregistrator-F" was used.

2.3 Experiment Results

The result of a real experiment on a laboratory bench in a resonant mode at XX is presented in the form of a graph (Figures 6, 7).

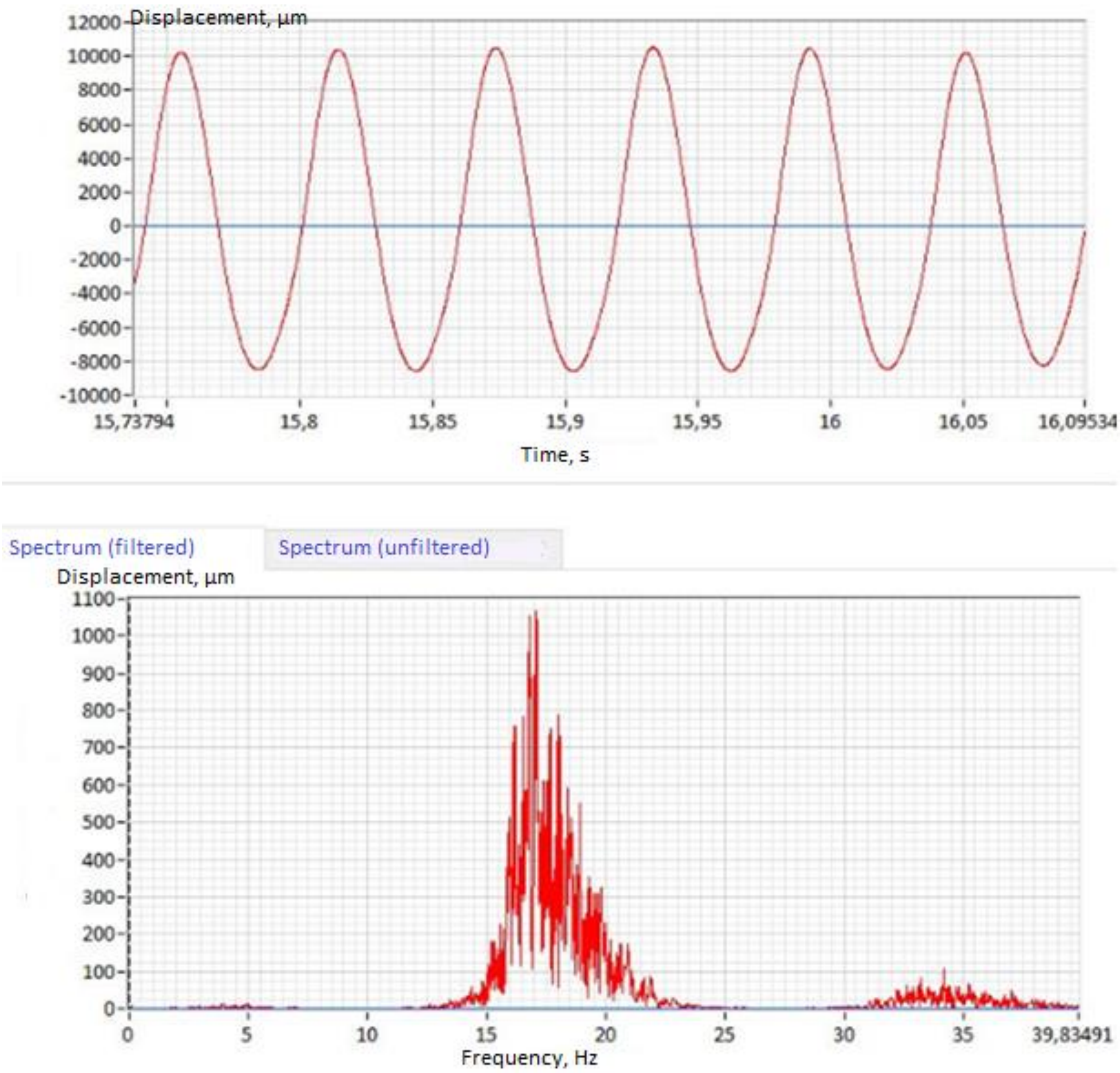


Fig.6. - Displacement and vibration spectrum of an oscillatory vibrator at a resonant operating mode of a laboratory stand at XX

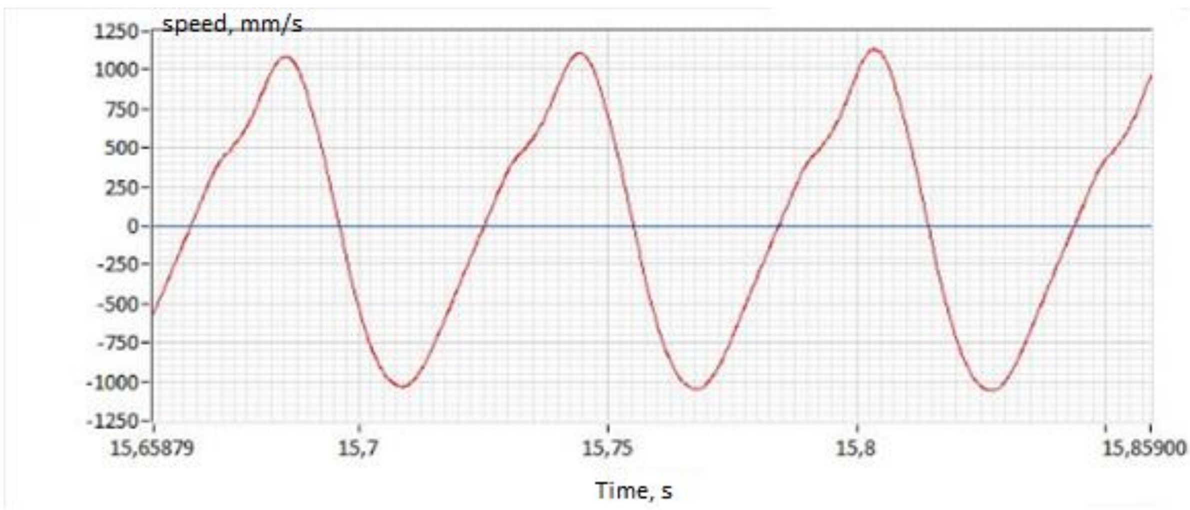


Fig.7. - The speed of the oscillating circuit at the resonant operating mode of the laboratory stand at XX

After correcting the mathematical model, a graph of the displacement and speed of the spacecraft was built (Figure 8), as well as the spectrum of oscillations of the oscillatory circuit (Figure 9).

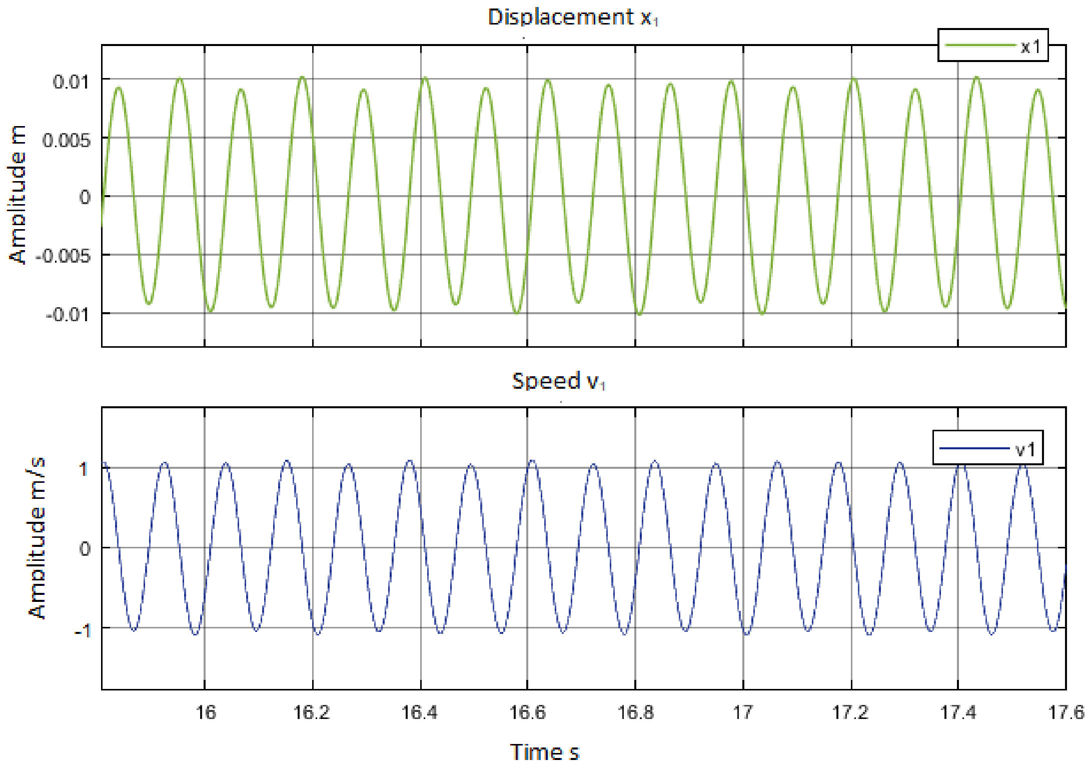


Fig. 8. - Displacement and speed of the oscillatory in resonance mode on the XX device with parameters from the laboratory stand

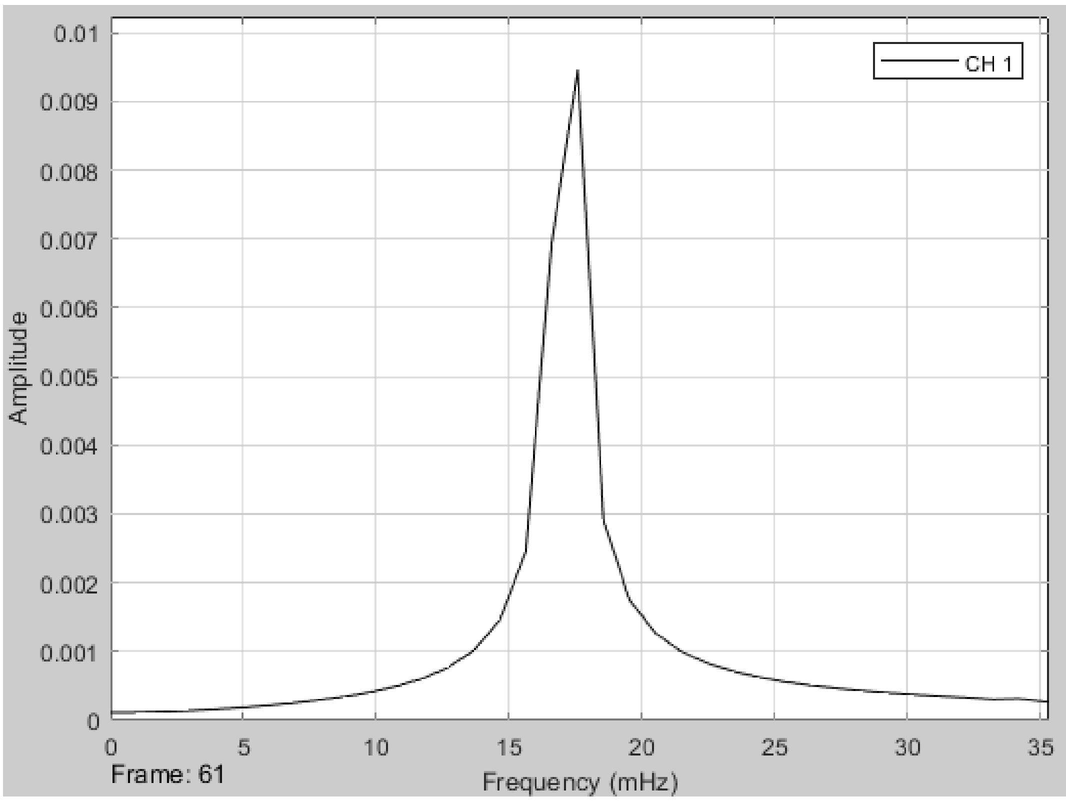


Fig. 9. - Spectrum of vibrations of the KK vibrator in resonance mode on the XX device with parameters from the laboratory stand

The amplitude of displacement of the oscillatory circuit based on the graph (Figure 8) is 9.6 mm, and the amplitude of the velocity is 1 m / s. The difference between real experiment and simulation is:

- displacement 0 mm (0%);

- speed 0.10 mm /s (1%);
- flow rate 0.00001 m^3 / s (4%);
- vibrator excitation frequency 0.8 Hz (5%).

The difference between real and simulated data is explained by the fact that in the work all parameters of the mathematical model are constants, but in practice they are not.

4. Conclusions

As a result of the study, it was found that:

- the dependences of the displacements, the speed of the oscillating circuit on the time in the resonant mode were obtained;
- received the dependence of the amplitude and frequency of the oscillatory circuit;
- the results obtained on the test bench are correct and adequate;
- the difference with the laboratory bench does not exceed 5%.

Thus, it can be concluded that the obtained dependence of the amplitude of displacement of the oscillatory circuit on the frequency of excitation of the oscillator of oscillations is not contradictory, moreover, experiments in the work confirm that it is correct.

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Information of the author

Kozyrev Alexander Nikolaevich, master student of the materials science department of Engineering School of New Manufacturing Technologies of Tomsk Polytechnic University
E-mail: kozyrev_alexandr@mail.ru

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Features of chip formation during thermal friction milling

Mussayev M.M.[1*], Sherov K.T.[2], Zharkevich O.M.[1]
[1]Karaganda Technical University, Karaganda, Kazakhstan
[2]S.Seifullin Kazakh Agro Technical University, Nur-Sultan, Kazakhstan
*corresponding author

Abstract: The article presents the results of a study of chip formation during processing of steel 30HGSA by thermal friction milling. When studying the process of chip formation, a metallographic research method was used. Investigated the zone of the root of the shavings, which is the most stressed zone and the zone of the highest pressure and intense heat generation. Chip samples were also obtained to study the texture. To improve the surface structure of the samples, they were pressed in, polished, and etched by the electrolytic method. In order to have more detailed information about the processes occurring in the zone of chip formation, a diagram of the formation of chips during thermo-friction milling was given. The results of the study showed that in the process of thermo-friction milling, no structural transformations occur, and the material in the contact layers retains the initial phase state and undergoes changes only due to plastic deformation.

Keywords: thermal friction milling, chip formation, chip root, structural angle, retarded layer, plastic deformation.

1. Introduction

The most important conditions for increasing the competitiveness of manufactured products are increasing productivity, reducing costs and improving quality in their production [1, 2].

In the modern machine-building industry of the Republic of Kazakhstan, especially in the mining and metallurgical complex, corrosion-resistant and heat-resistant steels and alloys are increasingly used, the processing of which by traditional methods of mechanical processing for Kazakhstani plants is associated with certain difficulties. These alloys are generally difficult to machine. Cutting tool wear is very high. For processing such materials, cutters equipped with plates made of expensive tool materials - hard alloys, mineral ceramics, elbor, etc. are mainly used.

One of the ways to save expensive tool material is the development and application of new resource-saving technologies for thermofrictional processing at low speeds [3, 4, 5], in particular, a complex method of friction milling [6, 7].

When turning hard-to-machine materials, one of the main reasons affecting the quality and productivity of cutting is the formation of drain chips of various shapes and sizes [8, 9]. With the creation of multifunctional lathes equipped with a tool head with its own drive, it became possible to carry out the milling operation, which eliminates the noted difficulties [10, 11].

The authors, within the framework of the grant theme AP08956387 "Creation of a prototype of a universal device based on a lathe for the implementation of milling technology", funded by the Ministry of Education and Science of the Republic of Kazakhstan, investigated the method of thermo-friction milling using a special cutting tool - a friction cutter.

One of the main differences of the developed method is the use of a special friction milling cutter made of non-instrumental material instead of standard end mills.

Studying and researching the process of shaving formation has both scientific and theoretical and practical significance [12]. The purpose of thermo-friction milling is to remove material to achieve the desired dimensions of the finished part.

It might seem that there are vastly different methods used in milling and turning; however, the basic principle of material removal by chip formation is the same for both.

This is all the more important in the development of new methods of cutting, where the results of the study of chip formation can lead to the improvement of the structural elements of the cutting tool, and will also make it possible to explain and correctly use in practice the force and resistance dependences.

In this regard, the work aimed at studying the mechanism of chip formation and the deformed state of the material during processing by thermofrictional milling is an urgent task.

2. Technique and equipment for research

The tasks set in the work were solved by experimental and theoretical methods. In theoretical studies, the main provisions of the theory of cutting materials, the theory of plasticity and elasticity, the theory of chip formation, metal technology, materials science are applied. In experimental studies, a metallographic method was used for microsections of the roots of shavings. The studies were carried out using the equipment of engineering laboratories (LIP) and MCM of the Karaganda Technical University.

Were used: CitoPress, automatic machine LaboPol-5 for grinding and polishing samples, automatic device for electrolytic polishing and etching of metallographic samples, universal metallographic microscope Altami MET 5T, metallographic microscope LOMO METAM PB-21. Thermal friction milling of 30KhGSA steel samples was carried out on a JET GH-1640ZX screw-cutting lathe using a special device.

3. Results and discussion

Figure 1 shows photographs of shavings obtained when processing steel 30KhGSA at various cutting conditions [7].

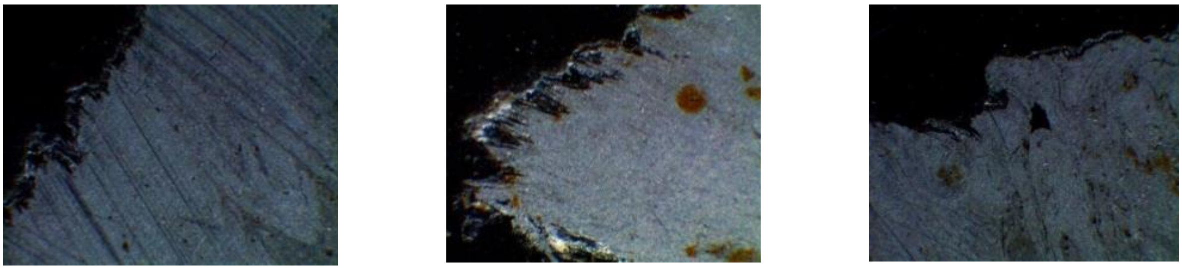
Fig.1. - Photographs of shavings obtained during processing of steel 30HGSA

To carry out a study to study the texture of the chips, samples (chips) of the same size were obtained, which makes fixation in automatic holders simple and convenient for further stages of preparation. To do this, we carry out hot pressing of chip samples on a CitoPress-1 press, in which the sample, together with a special resin for pressing, is placed in a press cylinder. Figure 2 shows samples of shavings obtained after pressing.

Fig. 2. - Samples of shavings obtained after pressing

After pressing in the chip samples, we grind them. Grinding is the most important operation in sample making technology. A LaboPol-5 grinding and polishing machine was used to grind the pressed-in specimens.

Abrasives used in grinding are classified by particle size. In the process of grinding, at first, the finest-grained material was used and each subsequent grinding operation was accompanied by a decrease in the grain size of the abrasive used. To improve the surface structure of the polished samples, the electrolytic etching method was used. This etching method gives not only a shiny smooth surface without the formation of work hardening or an amorphous layer, but also reveals structural defects (pores, inclusions, etc.). All operations were carried out on an automatic device for electrolytic polishing and etching of metallographic samples LectroPol-5. Figure 3 shows micrographs (at 50X magnification) of the texture of the chip samples.

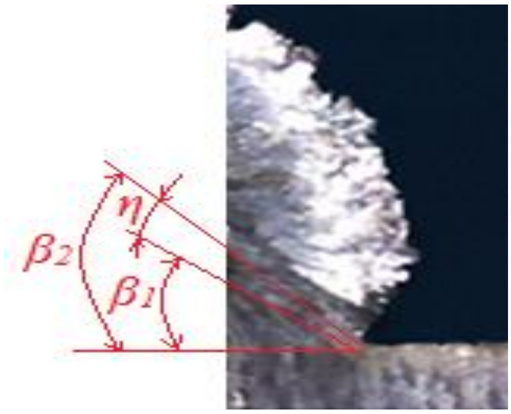


a) b) c)

Fig. 3. - Texture micrographs (with 50X magnification) of chip samples

Micrographs of chip samples were obtained using a universal metallographic microscope Altami MET 5T.

The micrograph of the texture shows that the lines of the texture are parallel to the front surface and there are no structural transformations during cutting. This is due to the fact that such a short period of time for structural transformations is insufficient, since in the process of thermo-friction milling, the tool and the workpiece rotate simultaneously. The material in the contact layers retains its initial phase state and undergoes changes only due to plastic deformation. To obtain a broader understanding of the process of chip formation during thermal friction milling, it is necessary to study the roots of the chips. Chip roots are direct evidence of certain processes occurring in the chip formation zone and in the contact zone. Research should cover a wide range of cutting speeds, only then it is possible to understand the transformation of mechanisms and processes in the cutting zone with changes in temperatures and deformation rates and draw appropriate conclusions. Figure 4 shows photomicrographs of the roots of the drain chips, obtained when cutting steel 30HGSA.



β_1- cleavage angle; β_2 – breakline angle; η - structural angle

Fig. 4. - Micrograph of the roots of the drain chips when cutting steel 30HGSA

Chip roots were obtained during semi-finishing turning of 30HGSA steel at feed S = 30 ÷ 100 mm / min; depth of cut t = 1.5 ÷ 2.5 mm; nsp = 2000 rpm; vi = 250 m / min.

It is known [14, 15, 16] that the basis for the formation of drain chips is mainly a simple shear. The direction of the plastic shear is determined by the angle β_1, and the direction of the texture is determined by the distortion of the grains due to the relative shear, which transforms them from spherical to ellipsoidal, and in a plane section - from circles to ellipses.

Here, the individual elements of the root of the drain chips are deformed in a direction that does not coincide with the position of the shear plane located at an angle β1. The destruction of the sheared layer occurs along the shear plane (Fig. 4), and the greatest plastic deformation occurs in the other direction, at an angle to this plane, at an angle β_2.

The structural identity of elemental and drain chips and the presence of two angles β_1 and β_2 (Fig. 4) and three zones with respect to the nature of the texture (Figures. 3 and 4) make one think that the nature of the formation of both chips is the same. This conclusion is also led by considerations of the unity of the cutting process, as well as the fact that in a number of cases one and the same chip includes both types [14]: on the one hand, it is elemental, on the other - drain.

An increase in feed increases the degree of deformation of the contacting layer of chips with the tool, therefore, the amount of heat released due to plastic deformation and the cutting temperature increase.

Therefore, the material of the shavings, which is near the point of contact with the tool and is the raw material for the build-up, softens and becomes very plastic. In this case, the build-up will not arise, grow and break down fragilely, but will flow in a thin layer along the front surface of the instrument in the direction opposite to its movement. The build-up on the surface of the instrument is in a plastic state and behaves like a pasty mass.

Since the cutting process during thermo-friction milling is carried out under difficult thermodynamic conditions, the braking effect exerted by the cutting tool becomes so great that it leads to a tight attachment of a part of the chips to the front surface and the formation of a hindered layer, which is clearly seen in the photographs obtained.

From this, the following conclusion can be drawn: in the area of plastic contact, the surface of the chips is so tightly pressed against the front surface of the tool that part of the chips moves not along the tool, but along the inhibited layer covering the front surface.

It is known that a hindered layer is usually formed when cutting plastic and viscous materials [14, 15]. In our case, the main reason for the formation of a hindered layer is the lack of cooling during thermal friction milling.

It should also be noted that in [13], it was assumed that during thermal friction milling, a current layer appears, due to which the chips slide in relation to the current stagnant layer, which protects the surface of the friction cutter from wear.

This phenomenon determines the features of thermo-friction milling as a process. For the emergence of the current layer, certain conditions are required, of which the most important and decisive is the proper temperature, which is concentrated in a small boundary layer.

Based on the available data [17], it can be assumed that the value of this temperature fluctuates within the value of the recrystallization temperature of the processed material.

4. Conclusions

1. It has been established that no structural transformations occur in the process of thermo-friction milling, and the material in the contact layers retains the initial phase state and undergoes changes only due to plastic deformation.

2. It was revealed that individual elements of the drain chip root are deformed in a direction that does not coincide with the position of the shearing plane located at an angle β_1.

3. It has been established that there is no build-up formation during thermo-friction milling, since the material of the shavings located near the point of contact with the tool and being the raw material for the build-up softens, becomes very plastic and will flow in a thin layer along the front surface of the tool in the direction opposite to its movement.

4. The main reason for the formation of a hindered layer when processing steel 30KhGSA, which is characteristic of the process of cutting plastic and viscous materials, is the lack of cooling during thermal friction milling. However, taking into account the fact that the cutting process during thermo-friction milling is carried out under difficult thermodynamic conditions, additional studies are required for a more detailed study of the formation of the hindered layer.

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Information of the authors

Mussaev Medgat Muratovich, PhD, acting associate professor of the department "Technological equipment, mechanical engineering and standardization" of Karaganda Technical University
E-mail: kstu_mmm@mail.ru

Sherov Karibek Tagaevich, doctor of technical sciences, professor of the department "Technological Machines and Equipment" of S. Seifullin Kazakh Agro Agrotechnical University
E-mail: shkt1965@mail.ru

Zharkevich Olga Mikhailovna, candidate of technical science professor of the department "Technological equipment, mechanical engineering and standardization"
E-mail: zharkevich82@mail.ru

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The concept of a wood chopping machine with a mechanical overload system ensuring continuity of work

Warguła Ł.[1*], Rosiak S.[1], Gierz Ł.[1], Gavrilin A.[2], Bykadorov S.A.[3]
[1]Poznan University of Technology, Poland,
[2]Tomsk Polytechnic University, Russia,
[3]Siberian State University of Railway Transport, Russia
*corresponding author

Annotation. The article presents a conceptual design of a wood chipper with a cutting mechanism equipped with a mechanical overload system. The innovative design (subject to patent application at the Polish Patent Office P.431435) ensures continuous operation of the chopping machines, even if wood enters the feed channel, the characteristics of which exceed the cutting ability of the cutting mechanism. A piece of wood with too high strength does not block the cutting mechanism and is not chopped in parallel, but is moved to the outlet channel of the machine. The solution facilitates the operation of the machine and prevents blocking of the mowing mechanism. The products of processed wood by the machine are wood chips and larger pieces of wood that exceed the machine's ability to cut. Wood chips can be used as biomass (in biogas plants, composting plants, incinerators), and larger pieces as firewood in central heating furnaces, e.g. in single-family houses.

Key words: wood chipper, wood shredder, wood crusher, wood size reduction machines, biomass, two-cylinder cutting mechanism, overload mechanism, synchronous gear, belt transmission with toothed belt, topological optimization.

1. Introduction

Air quality problems in urbanized areas force city authorities to take measures to increase green infrastructure [1,2]. Simultaneously, the increased human social awareness of the impact of plants on the quality of life also increases the number of trees on private properties [3,4]. These factors increase the demand for wood chopping machines equipped with a low power engine. Such machines differ significantly from choppers used in the forestry industry for the mass production of biomass. Industrial wood chippers are characterized by high power engines from 100 kW to 900 kW, and their cutting mechanisms are most often driven and controlled hydraulically [5,6,7,8]. On the other hand, the group of chopping machines most often used in urbanized areas is characterized by low-power engines [9,10]. In the regulations in force in the European Union concerning the emission limits of harmful exhaust compounds from engines used in non-road machines, low-power spark ignition engines are engines with a power of up to 19 kW [11]. These machines are characterized by a mechanical transmission of drive, most often through a V-belt transmission [12]. This transmission also functions as an overload clutch, which in unfavorable conditions may cause a fire in the machine [13,14]. Locking the cutting mechanism with wood with a strength greater than its chipping capacity stops the chipping process. Such a situation requires the unlocking of the mechanism and contributes to the point increased wear of the V-belt in the time between the lock of the mechanism and the engine shutdown [15]. Among the five basic cutting mechanisms in these machines (disc, drum, flail, one-cylinder and two-cylinder), two-cylinder is characterized by the highest productive and the lowest energy consumption [16]. On the other hand, it is one of the most susceptible to the mechanism blockage at the time of overload, unlike the drum chipper [16].

Searching for a solution reducing the problems with blocking the cutting mechanism, a construction with an innovative cutting mechanism was developed. The construction concept presented in the article ensures the continuity of the machine operation, regardless of the strength of the wood that is supplied to the cutting mechanism. The presented mechanism, in the event of the inability to cut the wood, pushes it into the outlet channel as a whole, producing two types of wood, chips and logs. The solution facilitates the operation, however, it is characterized by a more complex structure, in which one of the disadvantages is greater weight. It is important in this group of machines because they are often adapted to manual relocation and work on a soft or delicate surface, e.g. lawns. However, it is believed that modern methods supporting design may contribute to reducing the mass of innovative design solutions improving their functional properties [17,18,19, 20].

2. Problems of operation of low power two-cylinder chipper with classic overload mechanism

Overloading the two-cylinder wood chipper will result in the log blocking the mechanism completely. In order to protect the device in the construction of these machines, a protection in the form of an overload clutch is used. The safety (overload) clutch is the part that disengages the drive when the critical torque is exceeded. In low-power chippers, belt transmissions with a V-belt are used as overload clutches. When the mowing mechanism is blocked, the operator is forced to stop the machine completely (turn off the engine) and remove the wood that is blocking the mechanism (this often involves dismantling the covers). If the operator fails to notice that the mowing mechanism is jammed, the V-belt may be damaged. Since one pulley is blocked and the other pulley is still running, frictional skid on the running pulley causes an increase in temperature and damage to the belt (Fig. 1), details of this phenomenon are described in the works of Krawiec et al. [12,21].

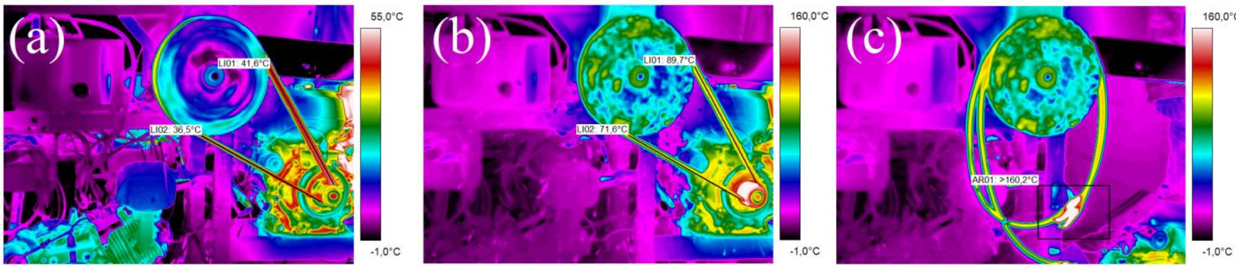


Fig. 1. – Problems of improper operation of belt transmissions with a V-belt during the performance of the overload clutch function, where: (a) normal operation, (b) blockage of a large pulley, (c) damage to the V-belt due to friction and high temperature [12]

3. The idea and principle of operation of innovative construction two-cylinder wood chipper

The classic cutting mechanism in the two-cylinder chipper (Fig. 2) is characterized by a non-divisible body and requires synchronous operation of the knives, which is ensured by a gear with gear wheels. The system is protected against overload by a belt transmission with a V-belt. The blockade of this system reduces the service life of the cable transmission and requires time and skill to unlock the mechanism. Employees and students of the Poznan University of Technology (PhD Eng. Łukasz Warguła and M.Sc. Eng. Szymon Rosiak) have developed an innovative design of a two-cylinder cutting mechanism without the possibility of blocking the cutting mechanism due to the influence of too durable wood. The solution is subject to patent application at the Polish Patent Office, application number P.431435 [22].

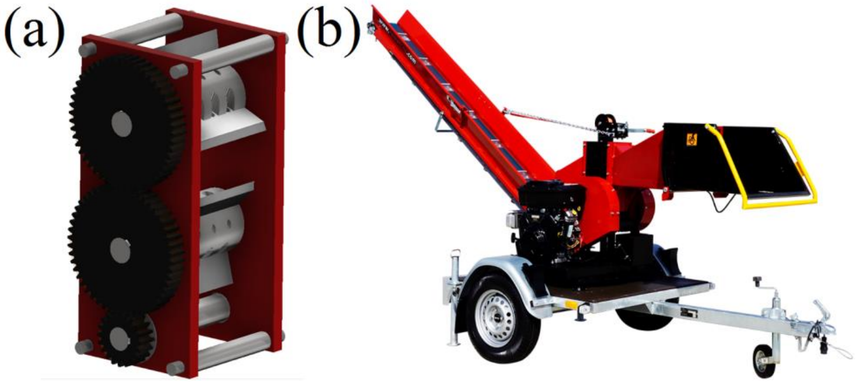


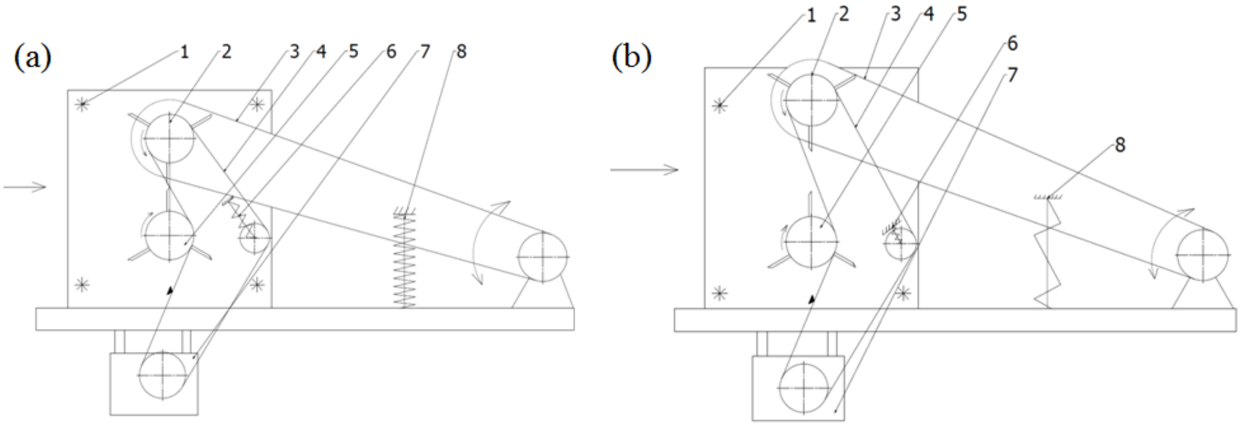
Fig. 2. – Two-cylinder chipper where: (a) cutting mechanism, (b) overall machine (Remet CNC Technology, Łowiska, Poland)

The solution according to the invention allows for chipping branches without interruption resulting from overloading the system with an object of too high strength, which characterizes the device with continuous operation.

The idea of the invention is realized in a chipper, the working member of which is made of two cutting rollers rotating in opposite directions, carrying out the cutting process by pulling the chipped material into the grinding chamber. By transporting the material to the outlet chamber in two forms: chips (the chipped material was characterized by the strength not exceeding the maximum breaking moment of the working member), the log (the chipped material was characterized by the strength exceeding the maximum cutting force of the working member).

The material, the size of which has not been reduced, is transported with the chips to the discharge channel where it can then be segregated. The two-cylinder wood chipper with overload system has an internal combustion engine with a drive pulley. The internal combustion engine is connected to the operating member by a belt transmission with a double-sided toothed belt and a mechanical tensioner with a belt tensioning spring. The working unit consists of two knife rollers, the lower knife roller on which the first pulley is mounted, and the upper knife roller on which the second pulley is mounted. The lower knife roller is mounted in the housing of the working unit and there are guide grooves in it. The upper knife roller is mounted in the rocker arm, attached to the chipper frame in the axis of rotation by means of a bolt connection. The tension of the rocker arm, and at the same time the working member, is regulated by the rocker arm tension spring attached to the chipper frame and rocker arm by means of pin connections.

The engine, through the belt transmission, drives the working unit consisting of two cutting rollers equipped with knives. The synchronization of the cutting roller with the knives enabling material cutting is ensured by a gear with a tensioning system. It also acts as a counterbalancing system in the case of material disintegration, which will not be fragmented due to the too low cutting moment of the device. Then, the working rolls, increasing the distance between the axes of rotation, push the non-comminuted material towards the outlet channel until the value of the cutting moment allows the material to be fragmented. This value is adjusted by a spring that presses the upper cutting roller, which is mounted on the rocker arm. The schematic diagram of the structure in two working positions is shown in fig. 3. The principle of operation and the ideas of the developed structure are in line with the modern trend of designing machines limiting the idle time of machines [23,24,25], which is a loss for the enterprise, in this case they are downtimes due to unlocking the cutting mechanism.



1 – housing connecting bolts, 2 – upper shaft with knives, 3 – rocker arm, 4 – gear a cable with a double-sided toothed belt, 5 – lower shaft with knives, 6 – tensioner, 7 – combustion engine, 8 – rocker arm spring

Fig. 3. – Schematic diagram of a two-cylinder chipper with an overload mechanism, (a) normal operation, (b) system operation under overload conditions

4. Model 3D

Based on the schematic diagram and analytical calculations in the field of the basics of machine design, a 3D model of the developed concept was developed. An example of the concept in the form of a structure is shown in Fig. 4. The model enables further work and simulation research on the development of the structure, eg topological analysis of the frame (rocker) of the upper cutting knife.

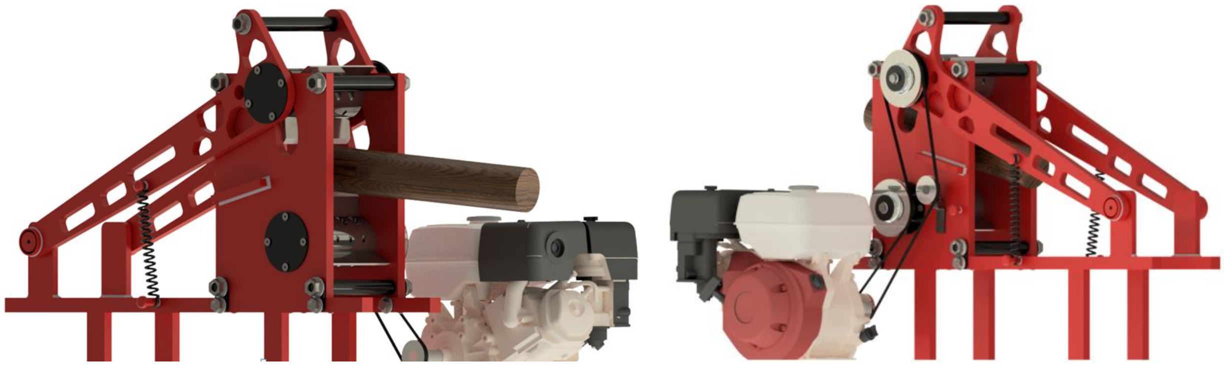


Fig. 4. – Model of the construction of a wood chipper

5. Numerical topological analysis

The new construction of the cutting mechanism of the wood chipper is characterized by an increase in the weight of the structure. One of the basic elements is the frame (rocker arm) of the upper mowing mechanism. These elements can undergo a mass reduction process using new design methods. In order to reduce the mass of the frame (rocker arm) of the upper cutting knife, topological optimization analyzes were performed in the Autodesk Nastran Solver program.

There are two rocker arms in the designed machine, hence the acting forces are divided in half and applied to the seat of the upper shaft bearing with knives (Fig. 5), the value of the applied force is 450N. Additionally, the arm is subjected to a force from the spring pressing the two cutting mechanisms (force value 400N). Restraint was given at the main frame pin bearing seat (Fig. 5). It can be noticed that the frame which has not been subjected to the topological optimization process is characterized by high strength, the maximum stresses equal 10.7 MPa (they are far from exceeding the permissible stresses) and are concentrated in the area of the restraint. For the tested frame, the material used was steel with increased strength parameters (S690QL steel), the value of its yield point is Re = 690 MPa, in the tested operating conditions, the frame may be subjected to unilaterally pulsating bending (0.35 ÷ 0.45 Re), one-sided bendig 240 MPa was adopted. also subjected to a deformation the value of which is also relatively small 0.25 mm (Fig. 6).

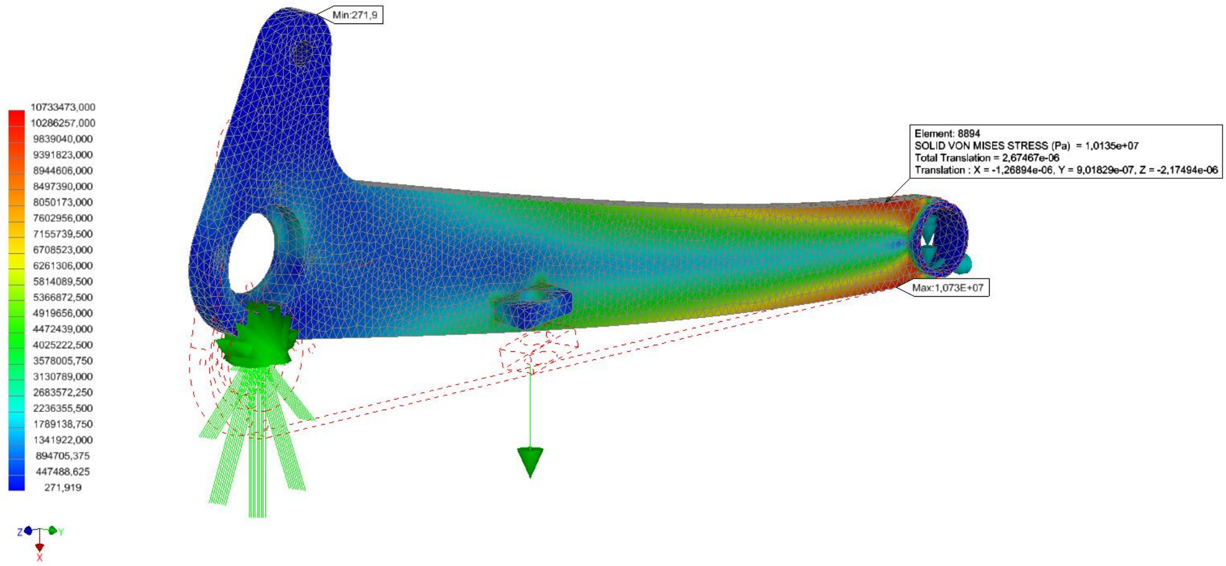


Fig. 5. – Huber von Mises stress analysis of the frame before topological optimization

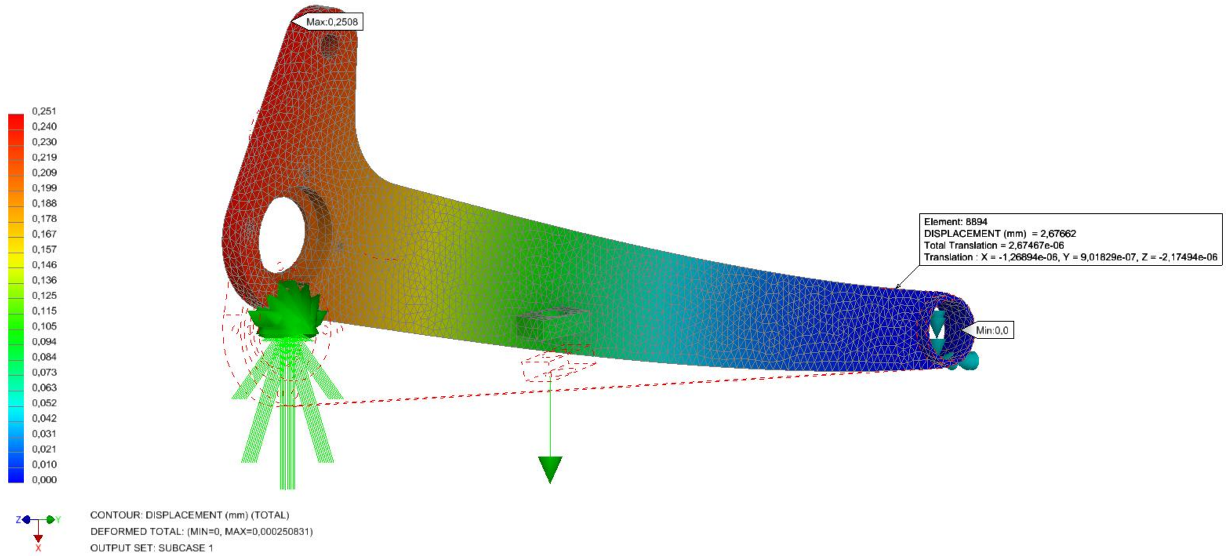


Fig. 6. – Frame deformation analysis before topological optimization

The tested frame was characterized by a mass of 12 kg, in order to reduce its mass, topological optimization assumptions were adopted - material reduction by 30%, which is equivalent to a mass reduction. The weight of the element after optimization was 8.44 kg. Most of the material was removed at the points where the least stress was present. The proposed frame with the material removed is shown in Fig. 7. The tested frame was also subjected to stress analysis (Fig. 8) and deformation (Fig. 9). The stresses and strains in the structure increased to the values of 16 MPa and 0.3 mm, respectively, not exceeding the safe and proper parameters of the structure for the proper functioning of the structure. The analysis made it possible to reduce the weight of the structure by about 7 kg (about 3.5 kg for one part of the frame).

Fig. 7. – Proposed frame geometry after the topological optimization process reducing 30% of the material in the least stressed areas

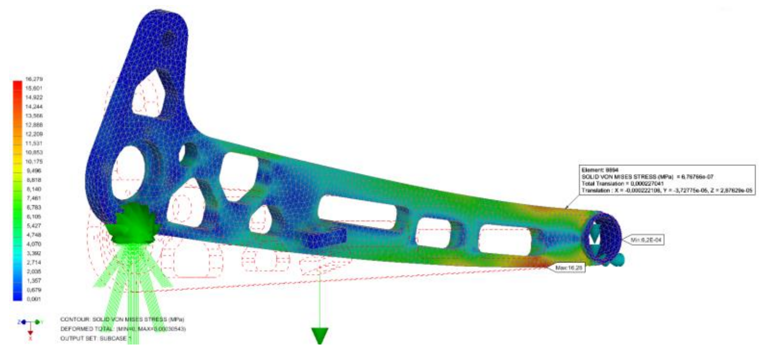


Fig. 8. – Huber von Mises stress analysis of the frame after topological optimization

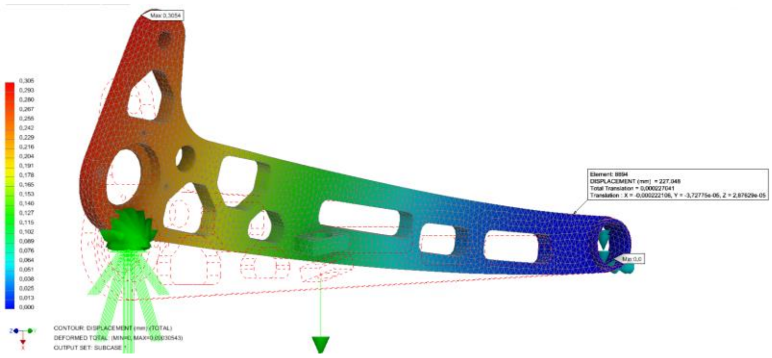


Fig. 9. – Analysis of frame deformation after topological optimization

6. Conclusion

It is possible to develop a wood chipping machine design where the cutting mechanism will not jam and stop when its ability to cut wood is exceeded. The presented cutting mechanism can grind the wood to the strength of which it is designed, and the remaining wood is transported to the outlet channel in full. Such a mechanism increases the weight of the device and is characterized by a more complicated drive gear. However, modern design methods can help and reduce the negative effects associated with introducing innovations. The developed results resulted in an innovative concept for the construction of machines reducing the size of the wood. Allowing to facilitate operation due to the inability to block the cutting mechanism and shortening the time for selecting and preparing, for example, branches for the chipping process with the selected machine. The developed machine can produce two types of wooden material: wood chips for gasification processes, composting plant and incinerator, and logs used in central heating furnaces in homes. The structure was developed and tested at the model stage, in the future a prototype should be made and the correct operation of the structure should be checked. In further research, it is possible to develop a system for the separation of chips and logs after the chipping processes with the described machine.

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Information of the authors

Warguła Łukasz, PhD, associate professor of the Faculty of Mechanical Engineering of Poznan University of Technology
E-mail: lukasz.wargula@put.poznan.pl

Rosiak Szymon, master of the Faculty of Mechanical Engineering of Poznan University of Technology
E-mail: rosiak_s@put.poznan.pl

Gierz Łukasz, PhD, associate professor of the Faculty of Mechanical Engineering of Poznan University of Technology
E-mail: lukasz.gierz@put.poznan.pl

Gavrilin Alexey Nikolaevich, doctor of technical sciences, professor of mechanical engineering department of Tomsk polytechnic university
E-mail: gawral@tpu.ru

Bykadorov Sergey Alexandrovich, doctor of economics science, professor of the department of "System Analysis and Project Management" of Siberian State University of Railway Transport
E-mail: byser@ngs.ru

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Concerning shaped parts milling using high speed machining

Buzauova T.M.*, Smagulov A.S.
Karaganda Technical University, Karaganda, Kazakhstan
*corresponding author

Abstract: The article presents the condition of shaped parts milling. Features of cutting in a high-speed machining (HSM) mode are considered in order to ensure quality and productivity in milling. Temperature dependence on cutting speed for high-speed machining is considered. Reasons of vibrations occurrence when HSM is applied are studied. Various methods of reducing vibration velocity and vibration acceleration of milling system are presented. Cutting process in a closed self-oscillating system is considered. The diagram of the stability zones is considered to select the optimal machining parameters.

Key words: shaped part, tool, high speed machining, cutting speed, CNC, rotation speed.

1. Introduction

On the issue of high-speed mashing, today there are many disputes about the effectiveness of this strategy, about various nuances, etc., there is not even a clear definition of what high-speed machining is.

High Speed Machining (HSM) is a machining methodology that focuses on extremely fast, yet light, low pressure cutting conditions. The result is an overall increase in material removal rate.

The goal of HSM is to use high speeds to achieve high material removal rates. To achieve successfully this goal, you need to understand eight basic principles:

- rigidity of the tool and workpiece;
- balancing instruments;
- testing instrument harmonics;
- controlled load on the tool;
- short tool steps;
- tool selection;
- understanding of the material;
- machine requirements.

High Speed Machining (HSM) and High Speed Milling (HSM), in particular, have significantly changed the approach to machining methods in recent years. The decisive factor in evaluating the HSM processing process is the productivity of the machines, which determines the cost of production and the improvement of the quality characteristics of the processing process.

The purpose of the article is to consider the issues of milling shaped parts to ensure quality and productivity in this machining process.

2. Results and discussion

Currently in mechanical engineering industry, shaped parts make up a significant proportion of manufactured parts. The basis for optimization and automation of mechanical machining of shaped parts is the use of machine with computer numerical control, hereinafter referred to as CNC. An important moment in the history of machines manufacturing is the development of high-speed spindles that increase productivity by high cutting speeds which enables to increase minute feed S_{min}, rather than by increasing chip cross sectional area (a_p and a_e) as was the case in the past:

$$Q = S_{min} a_p S_e \quad (1)$$

where a_p – axial depth, mm;
a_p – radial depth, mm;
S_{min} – minute feed, mm.

High Speed Machining is one of the new and rapidly developing technologies, the main principle of which is a small cross-section of a cut removed by a high cutting speed.

HSM was first mentioned after patent No. 523594 was published in Germany [1] in the name of Karl Solomon in 1931. He made the assumption that at a certain cutting speed, which is several times higher than during conventional machining, the heat transfer from a chip to a tool begins to decrease. If we depict this assumption as a function, placing cutting speed values along the abscissa axis, and the arising temperature along the ordinate axis, the resulting graph can be depicted as shown in Figure 1. This function describes the dependence of the temperature on the cutting speed, with an initial increase in speed the temperature rises to some critical value (point a) at which the tool loses its cutting properties. A further increase in speed leads to a slight increase in temperature, which at a certain moment begins to fall (area from point *a* to point *b*). After a slight drop in temperature, the growth resumes and after crossing the critical temperature line, the conditions for the instrument's operation become unfavorable (section after point *c*).

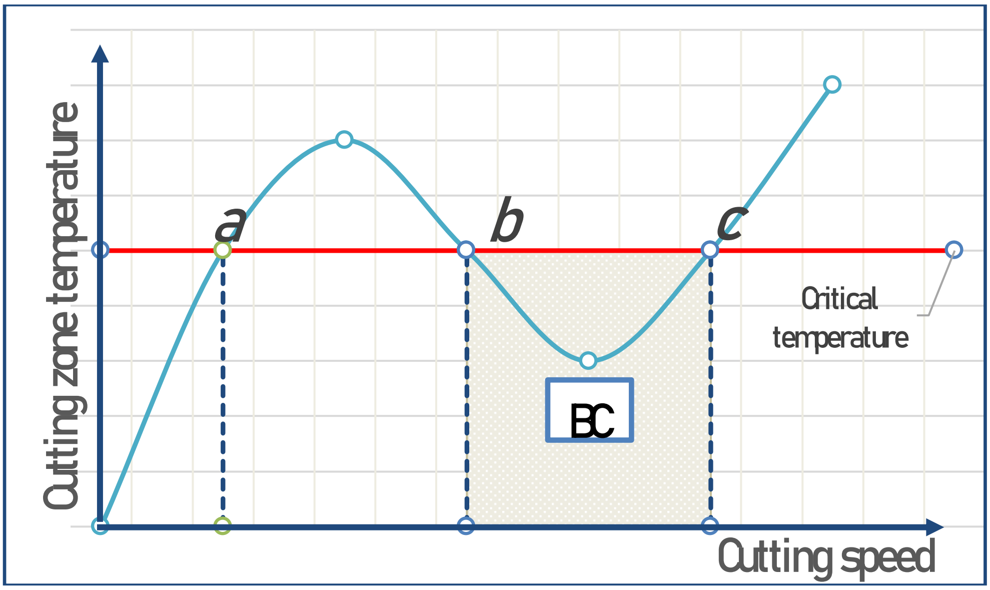

Fig.1. - Solomon Curve

Machining can be carried out in the classical form, the cutting speed interval of which corresponds to the area from 0 to point *a*. The area between points *b* and *c* corresponds to high-speed machining. In cases where the cutting speed interval is in the interval between points *a* and *b*, as well as in the section after point *c*, cutting by machining is undesirable, since in these cases the temperature will certainly be higher than the critical temperature for a given combination of tool material and work material.

One of the main problems when machining at high speeds is vibration. For a long time, vibrations were considered forced vibrations, but Woznick in his work [2] refuted this statement. Woznick proved that the vibration frequency does not change in a wide range of speeds. On the basis of this evidence, he concluded that vibrations arising from the cutting process should be considered self-oscillations.

Tlusty J [3] in his work in 1978 proposed a closed self-oscillation system for a part, tool and cutting process, shown in Figure 2. Based on this system, the calculation of the “processing stability limit” is made according to the “regenerative theory”.

As for the case of classic milling or turning, this system of part and tool is in continuous interaction with the cutting process, which is why the self-oscillating process occurs.

As for the case of milling of a shaped part, it is impossible to apply this scheme, since it occurs exclusively at the moment of cutting, which is periodically replaced by the free movement of a part. Hence, the system in direct relation to the angular position of the tool is either closed or open.

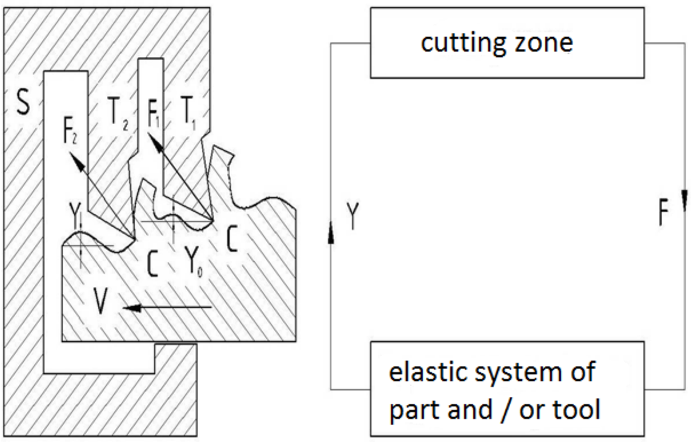

Fig. 2. – The cutting process, the system of a machine and a tool in a closed self-oscillating system proposed by Tlusty J

Zharkov I.G. [4] in his work offers various ways to reduce vibration velocity and vibration acceleration of milling system, one of the ways is damping, using additional structural elements in a machine. It is recommended to use anti-vibration equipment, if the total length of adjustment from the spindle end is exceeded equal to eight diameters of the end of a mill. It is recommended to use dampers for parts that are made of difficult-to-machine materials, as they increase productivity and ensure the required accuracy.

The efficiency of CNC machines is also affected by the tool geometry factor assigned by a technologist.

Shalamov A.V. and Mazein P.G. [5, 6] proposed a method that enables to quickly and automatically find the optimal parameters for finishing milling of shaped parts. They have solved the problem of optimizing the raster and spiral trajectories of movement of end spherocylindrical mill.

Using the diagram of the stability zones [7, 8] developed by the German company Siemens PLM Software, you can also select the optimal machining parameters. Several series of passes are performed on the tested workpiece with different spindle rotation speeds, while the feed per tooth remains unchanged for all passes of each series. Since the cutting process can run stably at different depths of cut, each successive series of passes increases the depth of a cut.

Optimum machining parameters are determined by the quality of the processed surface at each pass. The metal removal rate at each pass is determined by setting the values of the minute feed and the section of a cut layer, as shown in Figure 3.

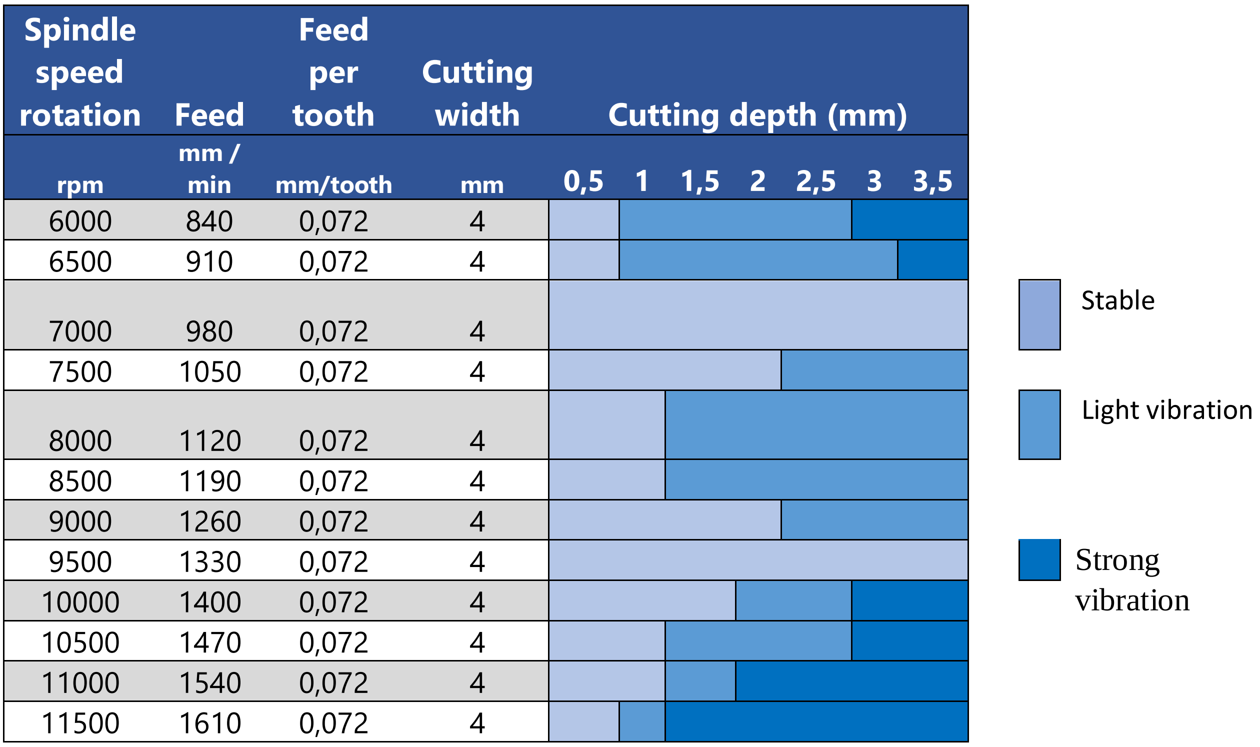

Fig. 3. - Diagram of stability zones

By using the software, the optimal spindle speed is calculated, which is used to analyze the acoustic information received through a microphone connected to a computer. A stable cutting process can be predicted by sound, since the sound recorded during the pass contains information for predicting the spindle speed [9,10]. This software reduces the number of workpieces and the time to find the optimal machining zones.

3. Conclusions

Based on the results of conducted analysis, it can be concluded that milling of shaped parts is intermittent machining, where cutting occurs periodically, alternating with the free movement of the part and the tool. This feature has different patterns for the process than for classic milling. So, for milling of shaped parts, the change in the magnitude of the driving force is significantly higher, because the process occurs at high impulse loads.

The process of organizing and maintaining self-oscillations has its own characteristics. In the environment of interrupted cutting, it is impossible to achieve steady-state self-oscillations. At the same time, in classical milling, self-oscillations always exist, but when milling of shaped parts, the situation is different.

The assignment of modes is a more complicated task that requires further research than with classical processing. At the same time, the ranges of cutting speeds and intervals of rotation frequencies are the most important criteria in which the tool loses its cutting properties and vibrations and crushing appear.

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Information of the authors

Buzauova Toty Meyerbekovna, candidate of technical science, associate professor of the department "Technological equipment, mechanical engineering and standardization" of Karaganda Technical University
E-mail: toty_77@mail.ru

Smagulov Altai Serikovich, master student of the department of the department "Technological equipment, mechanical engineering and standardization" of the Karaganda Technical University
E-mail: smagulovaltay@gmail.com

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Interaction LLP “KMZ named after Parkhomenko" with NJSC "Karaganda technical university" in the field of casting production

Surina V.V., Kuripko S.A.*
LLP “KMZ named after Parkhomenko", Karaganda, Kazakhstan
*corresponding author

Abstract: The history of the formation of the Karaganda Machine-Building Plant named after Parkhomenko is given. The line of products manufactured by LLP "KMZ named after Parkhomenko" is given. The goals of creating a branch at LLP "KMZ named after Parkhomenko" within the framework of cooperation with the Karaganda Technical University are indicated. The article analyzes the activities of the Department of Nanotechnology and Metallurgy of the Karaganda Technical University on the basis of the plant LLP "KMZ im. Parkhomenko ". LLP "KMZ im. Parkhomenko "is one of the oldest machine-building enterprises in Kazakhstan, specializing in the production of mining equipment. One of the main results of the interaction is to improve the quality of training graduates in the field of metallurgy and materials science. Along with the educational sphere, interaction affects research activities. Such interaction also allows the plant to compete with manufactured goods in the modern market.

Key words: materials science, branch, training, educational activities, research activities, production

1. Introduction

Karaganda Machine-Building Plant named after Parkhomenko (LLP "KMZ named after Parkhomenko") is one of the oldest machine-building enterprises in Kazakhstan, specializing in the production of processing, transport, mining equipment and spare parts for mining equipment.

LLP "KMZ im. Parkhomenko "began its activities with the production of special-purpose products for the front, and in December 1942 the plant switched to the production of mining, processing and individual equipment, which required the reconstruction of all production links of the plant, the construction of new workshops equipped with vehicles and the latest equipment [1].

The plant produces rather complex and unique equipment, which is manufactured by a few enterprises in the CIS. These include - screening - vibrating machines designed to separate materials by size; elevators - devices for vertical lifting of bulk materials, including dewatering and for transporting hot materials up to 200 °C; dust collectors are a whole class of machines for collecting dust at various enterprises, these are battery dust collectors, cyclones, wet dust collectors. In addition, it produces mine pushers, drum crushers, crusher-screen, plate feeder, vacuum drying chamber, drum dryer, etc. [2].

At “KMZ named Parkhomenko", a branch of the Department of Nanotechnology and Metallurgy (NTM) of the Non-Commercial Joint Stock Company "Karaganda Technical University" (NJSC "KarTU") has been operating for more than 10 years.

2. Results and discussion

The objectives of creating a branch of the Department of Science and Technology at the plant are: a combination of university theory and practical experience of leading industrial companies for organizing training for the teaching staff;

- creation of conditions for the development of a multilevel system of training, retraining and advanced training of specialists on the basis of the NTM department for LLP “KMZ named after Parkhomenko ";
- formation of the personnel reserve of the plant through targeted training of specialists in educational programs for bachelor's, master's and doctoral studies in the educational programs "Metallurgy" and "Materials Science and TNM";
- conducting research to ensure the competitiveness of enterprises through professional development and the development of managerial skills of their employees;
- conducting joint scientific research with the involvement of students on the basis of contractual relations for the creation of new technologies, equipment and materials that ensure an increase in the quality of training of specialists and the economic sustainability of enterprises;
- organization of educational and industrial practices, graduate design of students;
- strengthening the practical orientation of the educational process by transferring part of it to production.

An efficiently functioning branch of the department "NTM is a branch organized at LLP" KMZ named after A. Parkhomenko "in 2009. Since the establishment of the branch, more than 120 students have undergone industrial practice, laboratory work is carried out annually in the following disciplines: "Molding materials and mixtures", "Foundry technology", "Theory of heat treatment". Leading specialists of the plant were involved in delivering lectures at the Department of Science and Technology. 5 scientific and practical conferences "Materials quality management" were held, 9 scientific articles were prepared and 14 abstracts of reports were published in collections of international conferences, 7 field meetings of the AK were held on the defense of diploma theses and master's theses, joint textbooks and monographs are being prepared (Figure 1).

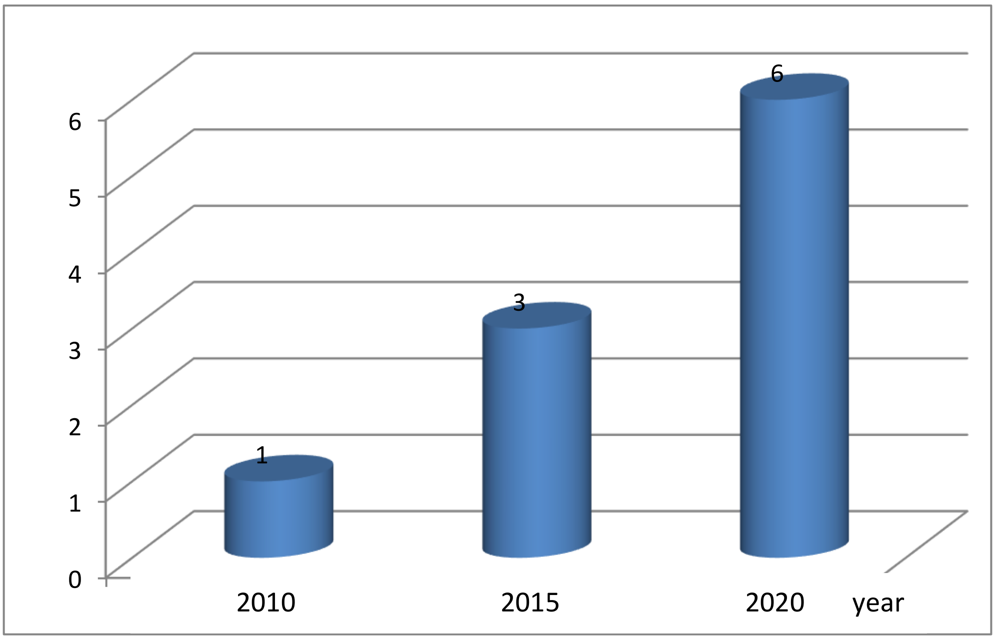

Fig. 1. - The number of published educational and methodological works, abstracts of reports together with the employees of LLP "KMZ named after Parkhomenko "

The Department of NTM is developing its experimental base, which is necessary for conducting both laboratory and practical exercises, and research work [3-5]. Due to this, a number of theses are annually carried out based on the results of scientific research carried out by students under the guidance of leading specialists of the department and LLP "KMZ named after Parkhomenko ". The share of research graduate works in recent years has been up to 50%. So, in 2020, 11 diploma theses of the educational programs "Metallurgy" and 7 diploma theses by students of the specialty "Materials Science and Technology of New Materials" were completed on the issues of the plant. For 2021, it is planned to carry out fourteen diploma theses by order of LLP “KMZ named after Parkhomenko".

The production capacity and high qualifications of the company's employees give students the opportunity to master the work with complex equipment, as well as the technology for obtaining new types of products.

As you know, a branch of the department is created in order to strengthen the relations of the university with production and to strengthen the practical training of specialists in the relevant specialty or direction of study.

Cooperation with LLP "KMZ named after Parkhomenko” favorably influences the quality of education of students, undergraduates and doctoral students. Among the advantages that this cooperation gives, the following facts should be noted:

- annually for all first-year students of the educational programs "Metallurgy" and "Materials Science and Technology of New Materials" excursions are held within the framework of familiarization practice (Figure 2), which enable students to see and learn how the main stages of the production process proceed in practice;

Fig. 2. - Practice of a student of the educational program "Metallurgy" in the position of a filler

- third-year students of the educational programs "Metallurgy" and "Materials Science and Technology of New Materials" in the amount of twenty people in each of the educational programs have the opportunity to undergo industrial and pre-diploma practice at the plant, during which they closely, at their workplaces, get acquainted with production, and also collect the necessary material for the graduation project;

- students and undergraduates of educational programs "Materials Science and Technology of New Materials" are provided with the necessary equipment for metallographic, mechanical and chemical laboratories for conducting experiments (Figure 3);

- conducting internships for teachers in the production conditions of the plant, which ultimately has a positive effect on the quality of training of future specialists. Five teachers of the department are trained annually in the foundry and forge-thermal shops;

- ensuring the familiarization of teachers and students with new samples of equipment and new technologies at the plant - this makes it possible not only to acquaint students with the already traditional equipment and technologies, but also to keep abreast of events taking place in the modern world. At the end of last year, the installation of a casting line for gasified models was completed (Figures 4, 5), a work that students and teachers had already had the opportunity to study.

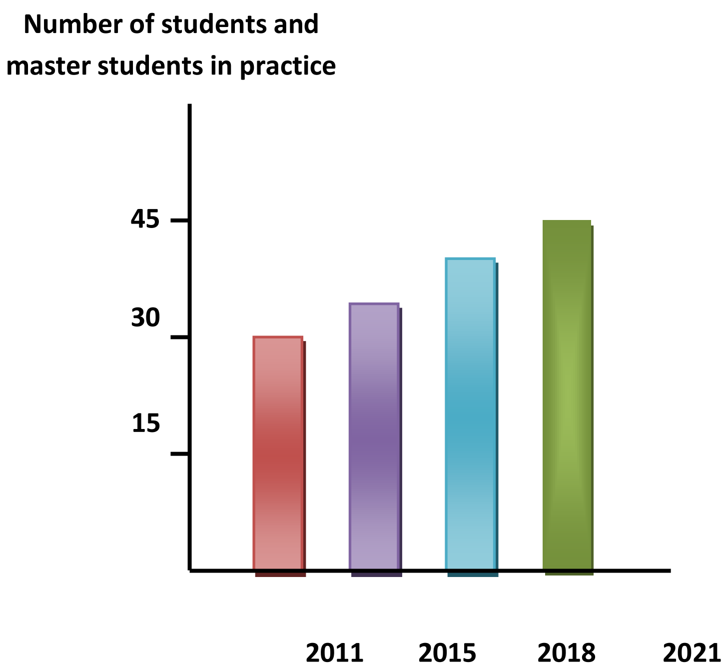

Fig. 3. - The number of students and undergraduates who completed internship at "LLP KMZ named after Parkhomenko "

Fig.4. - Equipment for the casting line for gasified models

Fig. 5. - Modern induction furnaces are available to students during internship

It should be noted that for the workers and engineers of the plant, the leading teachers of the department of scientific and technical technologies, lectures are given in the field of modern achievements of the foundry, which in turn serves the purpose of improving the qualifications of the workers of the plant.

Development prospects

Competent design, research, production and technological or organizational and managerial activity of graduates is possible only with a deep understanding of the essence of technological processes, as well as on the basis of their adequate modeling and comprehensive analysis. This requires good theoretical and practical training. The use of a branch of the department at LLP "KMZ im. Parkhomenko ”contributes to this and allows to achieve the necessary combination between theory and practice and enables a young specialist to respond flexibly to global trends in the field of metallurgy and materials science.

It is known that the main problems of foundry development are the following: technological backwardness of enterprises, low competitiveness of products; lack of contacts with world manufacturers, access to design documentation; insignificant amount of investments; lack of interfactory cooperation; high level of equipment wear and tear; shortage of qualified personnel; low level of after-sales service of engineering products. Functioning of the branch of the department of LLP "KMZ named after Parkhomenko” undoubtedly contributes to the elimination of these problems.

3. Conclusion

Thus, LLP "KMZ named after Parkhomenko "cooperates not only with machine-building organizations in the region, but also with educational institutions of the region, because in order to produce complex or new (recently mastered) equipment, it is necessary to have qualified personnel, which is graduated from Karaganda educational institutions. The enterprise has been cooperating with NJSC "KarTU" for a long time in the field of foundry, where our agreements always meet mutually beneficial conditions. There are joint successful projects aimed at extending the service life of products through special coatings.

Based on the foregoing, we can conclude that in the conditions of a developing market, the plant's products can compete in the field of mechanical engineering and metallurgy for other equally well-known enterprises.

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Information of the authors

Surina Valentina Vladimirovna, general director of KMZ named after Parkhomenko LLP
E-mail: kmz-imp@mail.ru

Kuripko Sergey Alexandrovich, chief designer of KMZ named after Parkhomenko LLP
E-mail: kuripko_a@mail.ru