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ТЕПЛООБМЕН В МЕТАЛЛООБРАБОТКЕ

Пособие для студентов, магистрантов и аспирантов
машиностроительных специальностей

HEAT TRANSFER IN METALWORKING

Manual for students, masters and postgraduate students
of engineering specialties

Новополоцк
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Рассмотрены основные виды теплообмена, дифференциальное уравнение теплопроводности и его решения, методы экспериментального определения теплоты и температуры при металлообработке, приведены результаты теоретического и экспериментального исследований температуры при охватывающем фрезеровании сферических поверхностей детали, дан пример расчета температуры в режущем инструменте при токарной обработке.

Для студентов, магистрантов и аспирантов машиностроительных специальностей, а также для преподавателей.

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INTRODUCTION

In connection with constant updating types of structural materials, increasing of requirements to quality of machine parts and intensification processing modes to the fore issues related to thermal processes in technological systems.

To consider these processes when designing the process equipment, to be able to manage them, you need to know, first of all, how is the heat transfer in the elements of the technological system.

1. PRINCIPAL OF HEAT TRANSFER

There are three types of heat transfer: conduction, convection and thermal radiation [1].

Conduction is the process of propagation of heat energy by direct contact of bodies or individual body parts, with different temperatures, for example, workpieces, tools and parts manufacturing equipment.

Convection is the process of moving volumes of liquid or gas in the space from one area to another, different temperature.

Convection of heat is always accompanied by conduction, since the movement of liquid or gas unavoidably contact of the particles having different temperatures.

A collaborative process of convection and conduction heat transfer is called convection.

Thermal radiation is the process of heat propagation in the form of electromagnetic waves with the mutual conversion of thermal energy to radiant and back again.

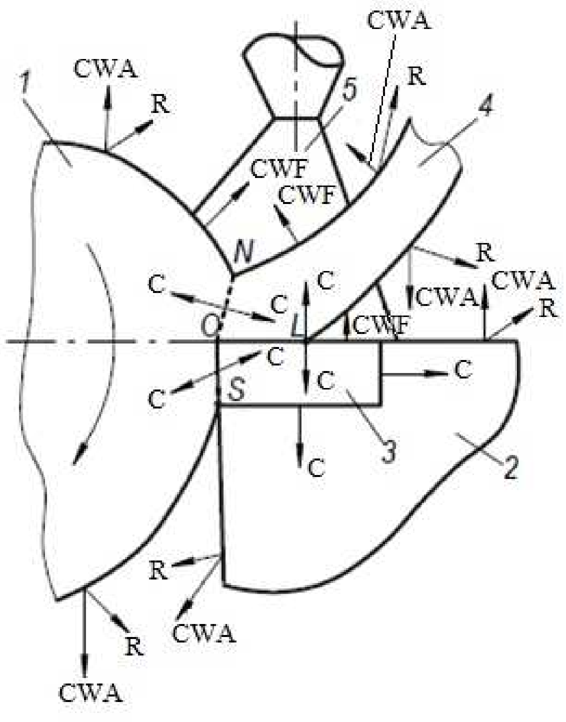

Figure 1

An example of the types of heat transfer during cutting is presented in figure 1, where C – conductivity, R – radiation, convection, CWF – convection with the fluid, CWA – convection with the air; ON, OL and OS – lots of heat from the deformation, the friction in the front and rear surfaces of the cutting tool.

The quantity of heat dQ flowing through isothermal surface with an area of dF for the time $d\tau$ is proportional to the temperature gradient (figure 2):

$$dQ = -\lambda \cdot grad\,\theta \cdot dF \cdot d\tau. \tag{1}$$

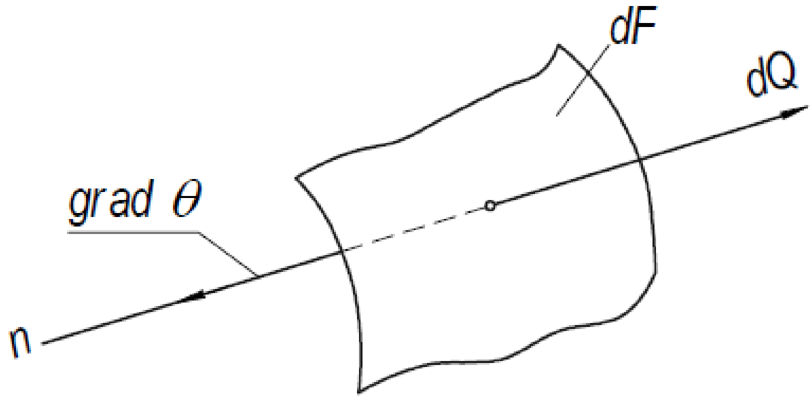

Figure 2

The amount of heat passing through unit area of the isothermal surface in unit time (heat flux density), is determined by the ratio:

$$q = dQ \,/\, dF \cdot d\tau = -\lambda grad\theta,$$

where λ – the coefficient of heat conductivity expresses the quantity of heat passing in unit time through unit area when the temperature gradient of one degree per unit length.

The thermal conductivity characterizes the ability of the material to conduct heat and depends on the composition of the substance, its structure, density, humidity and temperature. The minus sign in equation (2) shows that the vector of the heat flow directed in the direction opposite to the direction of the vector *gradθ*. Expression (2) typically represent the basic law of heat conduction, or *Fourier law* stating that the heat flux density is directly proportional to the temperature gradient.

2. THE DIFFERENTIAL EQUATION OF HEAT CONDUCTION

In unsteady mode the redistribution of heat is accompanied by a change in temperature of the individual elements of the body. The change in the temperature fields of solid bodies at non-stationary heat conduction is described by the differential equation. For the derivation of this equation will highlight in the body of the elementary volume ΔxΔyΔz (figure 3) 100, and consider the process of propagation of heat in it in the direction of one axis, for example OX.

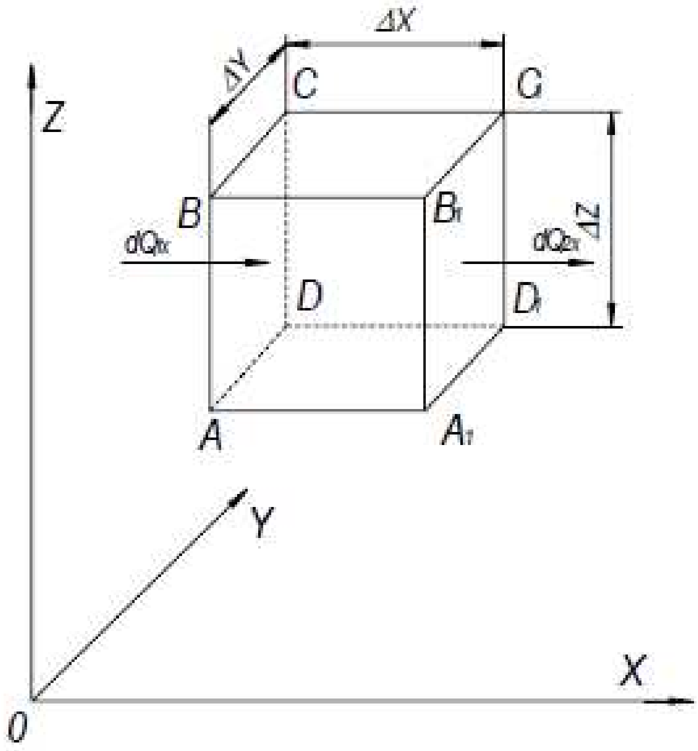

Figure 3

The smallness of area ΔyΔz, suppose that the temperature on each face of the body is distributed evenly. Let face A1B1C1D1 temperature is θ, and on the verge $ABCD - \theta' = \theta + \Delta\theta_X$, where the temperature change along the OX axis. The change of the heat flow from one face to another direction OX consider the body described by the expression:

$$dQ_{2x} = \lambda grad_x \theta \cdot \Delta y \Delta z \cdot d\tau$$

or

$$dQ_{2x} = \lambda \frac{\partial\theta}{\partial x} \cdot \Delta y \Delta z \cdot d\tau .$$

The temperature of the faces ABCD:

$$\theta' = \theta + \Delta x \frac{\partial \theta}{\partial x},$$

then

$$grad_x \theta' = \frac{\partial \theta'}{\partial x} = \frac{\partial}{\partial x}(\theta + \Delta x \frac{\partial \theta}{\partial x})$$

and heat flow

$$dQ_{1x} = \lambda \frac{\partial}{\partial x}(\theta + \Delta x \frac{\partial \theta}{\partial x}) \Delta y \Delta z \Delta \tau,$$

as $dQ_{1x} > dQ_{2x}$, in the amount of
or
Similarly, for the coordinate axes OY and OX:

$$dQ_x = dQ_{1x} - dQ_{2x} = \lambda \frac{\partial \theta}{\partial x} \Delta y \Delta z d\tau + \lambda \frac{\partial^2 \theta}{\partial x^2} \Delta y \Delta z \Delta x d\tau - \lambda \frac{\partial \theta}{\partial x} \Delta y \Delta z d\tau = $$

$$= \lambda \frac{\partial^2 \theta}{\partial x^2} \Delta y \Delta z \Delta x d\tau.$$

The change of the heat flow in the whole body will be described by the expression:

The amount of heat can also be determined using the heat capacity:

$$dQ_x = \lambda \frac{\partial^2 \theta}{\partial x^2} dV d\tau, \tag{3}$$

$$dQ_y = \lambda \frac{\partial^2 \theta}{\partial y^2} dV d\tau, \tag{4}$$

$$dQ_z = \lambda \frac{\partial^2 \theta}{\partial z^2} dV d\tau, \tag{5}$$

$$dQ = dQ_x + dQ_y + dQ_z = \lambda (\frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2} + \frac{\partial^2 \theta}{\partial z^2}) dV d\tau, \tag{6}$$

$$dQ = \rho \cdot c \cdot dV (\frac{\partial \theta}{\partial \tau}) d\tau, \tag{7}$$

where ρ – the density of the material;

c – mass heat capacity;

$\rho \cdot c$ – volumetric heat capacity;

$\frac{\partial\theta}{\partial\tau}$ – the rate of change of temperature of the body in time.

Equating the expression (6) and (7), we obtain the differential heat conduction equation of Fourier:

$$\frac{\partial\theta}{\partial\tau} = \omega\left(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2} + \frac{\partial^2\theta}{\partial z^2}\right), \tag{8}$$

where $\omega = \frac{\lambda}{c \cdot \rho}$ – the thermal diffusivity characterizing the thermal inertia properties of the body.

This equation is general and valid for any body shape and any conditions of heat transfer.

3. THE SOLUTION OF THE HEAT EQUATION

Given the above assumptions, the conduction equation can be solved in one of the following methods: classical, operating, numerical, heat sources and modeling.

When using the *classical method* is the integration of the differential equation (8) is one of the well-known mathematical methods. *Operating methods*, for example, in the method of integral Laplace transform is studied is not the function we are interested, and its modification obtained by multiplying on an exponential function. When using *numerical methods* for differential heat conduction equation is solved by finite difference method. It is based on replacing the derivatives in equation (8) by their approximate values, expressed by dierences of the functions $\theta(x, y, z, \tau)$ in discrete points-nodes of the grid (after the body is split into elementary volumes of the correct form). The differential equation in this case is replaced by the equivalent ratio of finite differences, the solution of which the algebraic operations are implemented on the computer. To determine the temperature at any point of the body in a given time, enough to know the temperature of the neighboring points at the previous time. If you know the initial temperature distribution in the body and on its boundary surfaces, then gradually, step by step, moving from one point of the body to another, or considering one time after another, can calculate the temperature field in the object.

The most widely used in various fields of engineering *method for the heat sources*. The essence of this method is determined by two main provisions:

1) temperature field arising in a heat-conducting body under the influence of a heat source of any shape, moving or stationary, the current is temporarily or continuously, can be obtained as the result of a particular combination of temperature field arising under the action of instantaneous point sources;

2) the process of propagation of heat in the body is in the form of the distribution of heat in the body of unlimited size by adding the actually existing sources a system of fictitious sources or heat sinks.

If we assume that in the body, all points which have the same temperature, and the heat exchange with the environment is missing, broke, and instantly extinguished the point source contributing the qT of heat, the solution of the differential equation (8) for these conditions can be written as:

$$\theta_T(x, y, z, \tau) = \frac{q_T}{\lambda\sqrt{\omega}(4\pi\tau)3/2} \exp \frac{-(x_u - x)^2 + (y_u - y)^2 + (z_u - z)^2}{4\omega\tau}, \qquad (9)$$

where $\theta_T(x, y, z, \tau)$ – the temperature of any point of the body;

x, y, z – the coordinates of the point of the body;

x_u, y_u, z_u – the coordinates of the heat source;

τ – the duration of the source;

λ and ω – accordingly, the coefficients of thermal conductivity and thermal diffusivity of the body material.

Modeling of thermal processes carried out mainly in two types:

1) physical modeling when studying the heat transfer process in a real body is based on analysis of similar process of propagation of heat in the model;

2) mathematical modeling when studying heat transfer in a real body is based on the analysis of fundamentally different physical phenomena, different from the process of propagation of heat, but having a similar mathematical description.

4. METHODS OF EXPERIMENTAL DEFINITION OF HEAT AND TEMPERATURE ELEMENTS OF THE TECHNOLOGICAL SYSTEM

Experimental determination of heat and temperature in the technological system it is necessary when solving heat problems empirically and to test theoretical calculations of temperature.

Methods of determining temperature are divided into *direct* and *indirect* [4]. To include *indirect* methods of estimation of temperature values for some of its indirect manifestations. For example, to change the component of the cutting force P_Z, because the amount of heat is determined by the formula $Q = P_Z \cdot \upsilon$. *Direct methods* are based on a relatively more accurate determination of temperature using temperature sensors. Direct methods, in turn, are divided into *contact* and *contactless*. *Contact* include methods and devices in which between the temperature sensor and the measurement object, there is no direct contact. The *contactless* methods, in which the measuring sensor devices located at some distance from the object whose temperature is to be determined.

Contact methods

If contact methods are used thermometers, thermoindicators, thermocouple; contactless – radiation and other devices, optical, acoustic and pneumatic sensors. Due to the nature of the temperature measuring elements of the processing system thermometers (mercury gauge and mechanical) are mainly used to determine the temperature of liquids, melts and when calibrating. Also limited the use of thermoindicators, which are divided into chemical, thermal and melting. Thermoindicators issued in the form of heat pencils, thermoablation, termotronic, heat-sealing and thermal paper. Thermoindicators have a temperature measuring range from 20 °C to 1500 °C and a few color changes (from 1 to 6). Each color indicates a certain temperature. For example, a fluoride of cobalt in Coo2 by the color orange, and at a temperature of 85 °C it becomes light pink.

Thermoindicators in the form of fusible inserts are substances which in a certain temperature range, pass into the liquid crystalline state. As these substances often use tin (θ_f = 231,9 °C), cadmium (θ_f = 320,9 °C), zinc (θ_f = 419,5 °C), silver (θ_f = 960 °C), copper (θ_f = 1083 °C).

Direct methods the most widely used methods using thermocouples, calorimeters and radiation pyrometers.

A thermocouple is the junction of two dissimilar metals, a common point which is called the hot junction, and all other dissimilar metals A and b in the circuit of the thermocouple, called cold junctions (figure 4).

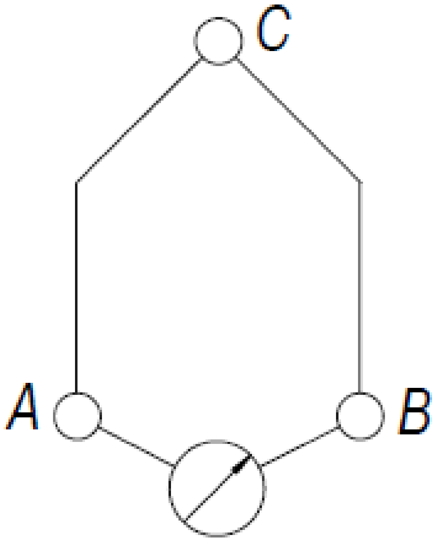

Figure 4

In the thermocouples used phenomenon, which is that in the closed circuit of two dissimilar metallic conductors by heating one of the junctions an electric current or so-called thermal electromotive force (thermal EMF). The thermocouple records the temperature difference between the hot and cold junctions. The cold junctions can be maintained at room temperature or zero temperature, which is achieved by locating the cold junctions in a vessel with melting ice.

Non-contact methods

Calorimetric method is the use of containers with liquid (water) and 1 for trapping flying off the chips 2, which are installed under the treatment area (figure 5)

After getting chips in a calorimeter, the water is stirred to equalize the temperature. After stirring, measured the water temperature, then the chips are weighed on an analytical balance and the weight of the chips, the temperature of the water in the calorimeter is calculated enthalpy of chips in calories and its volumetric average temperature:

$$\theta = \theta_m + \frac{G_w(\theta_m - \theta_w)}{c \cdot G}, \qquad (10)$$

where θ_m – the temperature of the mixture (water after being hit by a chip);

θ_w – initial temperature of water;

G_w – the mass of water in calorimeter;

G – the mass of the chip or of the cutter;

c – the heat capacity of the shavings or cutter.

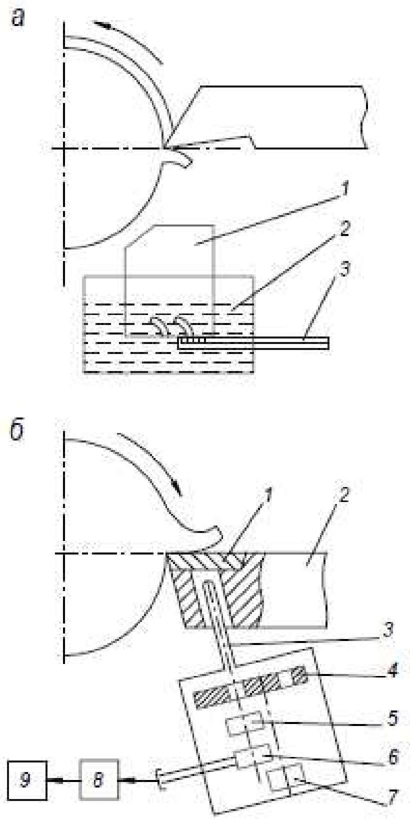

Figure 5. – **Schematic of temperature measurement of cutting with a calorimeter (a) and radiation thermometer (b)**

The radiation method is based on measurement of infrared radiation in the cutting zone radiation pyrometers (figure 5, b). Insert 1 cutter 2 needs to be transparent, for example, diamond, for the infrared rays, which through the light guide pads 3 fall to the modulator 4 and then through the filter on the radiation receiver 6. To drive the modulator 4 uses the micro 7. Infrared radiation is amplified by an amplifier 8 and is recorded by the device 9. This method is effective, but its use during cutting is restricted to small areas of the zone of heat radiation and its closeness.

5. THEORETICAL STUDY OF THE TEMPERATURE IN THE WORKPIECE WHEN COVERING MILLING

With high-speed milling of spherical surfaces, it is important to know the temperature in the workpiece, since the temperature deformation has a significant impact on the accuracy and quality of the part.

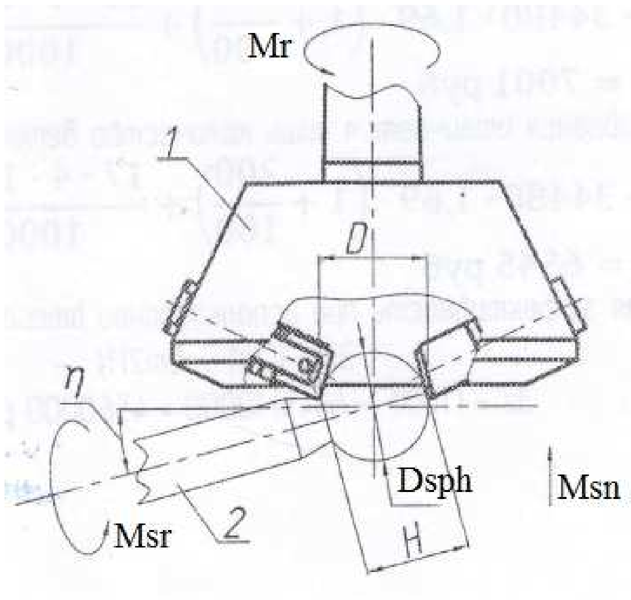

Figure 6

The scheme of the combined treatment of the clamp spherical surface of the part is shown in figure 2. According to this scheme, the cutting tool 1 makes the main rotational motion of the Mr, and the workpiece 2 diameter Dsph is rotational motion of the supply Msr. The workpiece is also reported forward motion Msn, which provides rotation to a predetermined depth of cut. In this case, the cutting blades of the tool 1 are adjusted to the diameter D, and the workpiece 2 is installed relative to the tool at an angle to the axis of rotation η. The axes of rotation of the workpiece and the tool intersect at one point. The installation scheme provides an incomplete limited on one side of the spherical surface height H. Kinematic cutting scheme when inserting a rotating tool into a rotating workpiece is a three-element (Mr, Msr, Msn) and nursing (smoothing), when the translational motion is interrupted Msn, goes into a two-element (Mr, Msr). A complex cutting path is realized in the form of a cycloid bent into a spiral or circle and intersecting the latter.

For theoretical studies, known [2] mathematical formulas were used to calculate the temperature in the cylindrical and spherical bodies, since the workpiece in the case under consideration has the shape of a cylinder, and the finished part – the shape of the ball.

For the cylinder:

$$\frac{\partial\theta}{\partial t} = k\left(\frac{\partial^2\theta}{\partial r^2} + \frac{1}{r}\cdot\frac{\partial\theta}{\partial r} + \frac{1}{r}\cdot\frac{\partial^2\theta}{\partial\mu} + \frac{\partial^2\theta}{\partial z^2}\right) + \varphi\frac{\partial\theta}{\partial\mu} \tag{11}$$

For the sphere:

$$\frac{\partial\theta}{\partial t} = k\left(\frac{\partial^2\theta}{\partial r^2} + \frac{2}{r}\cdot\frac{\partial\theta}{\partial r}\right). \tag{12}$$

It is accepted that the heat source is fast-flowing, since the rotation speed of the cutter reaches 10 m / s and the Baking criterion *Pe > 10:*

$$Pe = 10\frac{\nu\cdot l_n}{K}. \tag{13}$$

The schematization of the heat source by [3] is adopted, which is shown in Figure 7

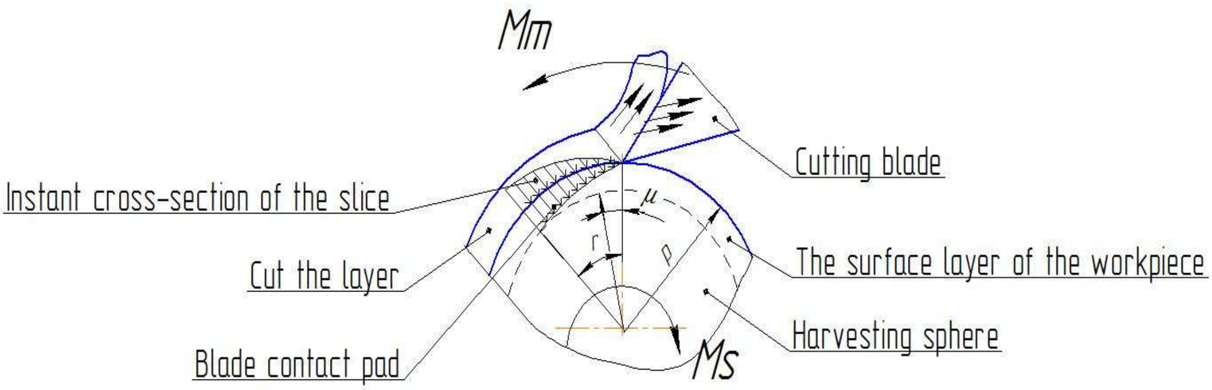

Figure 7

We analyzed the results of studies on the kinematics of cutting, deformation, dynamics, thermal phenomena, surface roughness and precision, wear of cutting tools during the machining of the surfaces of the spheres cutting. Features and advantages of high-speed cutting for processing of spheres are revealed.

On the basis of the analysis of literary sources objects and directions of researches in the given dissertation are defined.

In the side Chapter describes and analyzes the possible kinematic cutting scheme obtained with the ratio of the circumferential velocity of the tool and the workpiece, and their impact on the roughness of the machined surface, the geometry of the tool blade and the cross-section of the cut layer in the cutting process.

Through platforms of contact in the form of "comma" thermal streams from a cutting zone direct in preparation, a shaving and a tooth of the tool. The contact length was determined by an empirical formula:

$$l_S = l \cdot \sin^{xl}\tau, \tag{14}$$

where τ – contact angle;

l – the coefficient representing the soda value of the contact length at $\tau = 90°$

$$l = \frac{c_l \cdot S^{Ye}}{\left(\upsilon_p / \upsilon_t\right) \cdot z_l}.$$

The temperature from the point heat source according to [4] is described by the following equation:

$$\theta_{p.s.2}(r,\mu,z,\tau) = \frac{q_{p.s.2}\exp\left[-\dfrac{z^2}{4k(\tau-\tau_s)}\right]}{\pi \cdot R^2 \cdot \lambda \cdot \sqrt{\pi \cdot k \cdot (\tau-\tau_s)}} \cdot [1 + \sum_{n=-\infty}^{\infty} \cos n(\mu-\mu_s) \cdot$$
$$\cdot \sum_{\alpha} \frac{\exp\left[-k \cdot \alpha^2 \cdot (\tau-\tau_s)\right] \cdot \alpha^2 \cdot \ln(\alpha r) \cdot \ln(\alpha r_s)}{\left(\alpha^2 - \dfrac{n^2}{R^2}\right) \cdot \ln^2(\alpha R)}], \tag{15}$$

where r, μ, z – the coordinates of the point of the cylinder;

r_s, μ_s, z_s – the coordinates of the heat source;

τ – current time;

τ_s – the duration of the heat source;

$q_{p.s.2}$ – the intensity of the point heat source;

k – coefficient of thermal conductivity of the body;

λ – coefficient of thermal conductivity of the body;

$\ln(x)$ – the Bessel function of the n^{th} order of the first kind from a real argument;

$\sum_\alpha$ – using the sum of the positive roots of the characteristic equation $\alpha \cdot \ln'(\alpha R) = 0$.

Entry conditions:

$$0 \le \mu \prec 2\pi; 0 \le r \le R; 0 \le z \le \infty,$$
$$\tau > 0; \tau|_{\tau=0} = 0; \tag{16}$$

Boundary condition:

$$\frac{\partial\theta}{\partial r}\mathrm{I}_{r=R}^{=0}. \tag{17}$$

The formula for calculating the temperature in the workpiece when exposed to a temperature source in the form of a "comma" is obtained in the following form:

$$\theta_{s.2} = \frac{q_{s.2}\exp\left[-\frac{z^2}{4k(\tau-\tau_s)}\right]}{R^2\cdot\lambda\cdot\sqrt{\pi\cdot k\cdot(\tau-\tau_s)}}\cdot[l\cdot\sin^{xl}\mu\left(R-\frac{1}{2}\cdot\sin^{xl}\mu\right)$$
$$+2\sum_{\alpha}\frac{\exp\left[-k\cdot\alpha^2(\tau-\tau_s)\right]\cdot\mathrm{I}_0(\alpha\cdot r)}{\mathrm{I}_0(\alpha\cdot R)}\cdot\int\limits_{R-l\cdot\sin^{xl}\mu}^{R} r_u\cdot\mathrm{I}_0(\alpha\cdot r)\cdot dr_s]. \tag{18}$$

If the source is valid for the time from 0 to τ_s, then formula (18) is converted to the following form.

$$\theta_{s.2}(r,z,\tau) = \frac{2q_{s.2}}{R^2\cdot\lambda\cdot\sqrt{\pi k}}\cdot\{l\cdot\sin^{xl}\mu\left(2R-l\sin^{xl}\mu\right)\cdot$$
$$\cdot\left[2\sqrt{\tau}\cdot\exp\left(-\frac{z^2}{4k\tau}\right)-\frac{z\sqrt{\pi}}{\sqrt{k}}\cdot erfc\left(\frac{z}{2\sqrt{k\cdot\tau}}\right)\right]+\frac{\sqrt{\pi}}{\sqrt{k}}\cdot \tag{19}$$
$$\cdot\sum_{\substack{\alpha\\ \alpha\neq 0}}\frac{\exp(-\alpha r)\cdot\mathrm{I}_0(\alpha r)}{\alpha\cdot\mathrm{I}_0^2(\alpha R)}\cdot\int\limits_{R\cdot l\sin^{xl}\mu}^{R} r_s\mathrm{I}_0(\alpha r_s)\cdot\int\limits_0^{\alpha\sqrt{k\tau}}\exp\left[-\left(\frac{z\alpha}{2x}-x\right)^2\right]dx\}.$$

For quite a long time to work out the ($\tau\to\infty$) formula (18) is presented in the form:

$$\theta_{s.2}(r,z,\tau) = \frac{2q_{s.2}}{R^2\cdot\lambda\cdot\sqrt{\pi\cdot k}}\cdot\{l\cdot\sin^{xl}\mu\left(2R-l\cdot\sin^{xl}\mu\right)\cdot$$
$$\cdot\left[2\cdot\sqrt{\tau}\cdot\exp\left(-\frac{z^2}{4k\tau}\right)-\frac{z\sqrt{\pi}}{\sqrt{k}}\right]+\frac{\sqrt{\pi}}{\sqrt{k}}\cdot \tag{20}$$
$$\cdot\sum_{\substack{\alpha\\ \alpha\neq 0}}\frac{e^{-\alpha_z}\mathrm{I}_0\cdot(\alpha r)}{\alpha\cdot\mathrm{I}_0^2\cdot(\alpha R)}\cdot\{\frac{R}{\alpha}\mathrm{I}_1(\alpha R)-\frac{R-l\sin^{xl}\mu}{\alpha}\cdot\mathrm{I}_1\left[\alpha\cdot R-l\sin^{xl}\mu\right]\}\}.$$

According to the obtained formula (20), temperature calculations were carried out at different angles of contact of the cutter tooth with the workpiece and the following graphic dependence was obtained (figure 8).

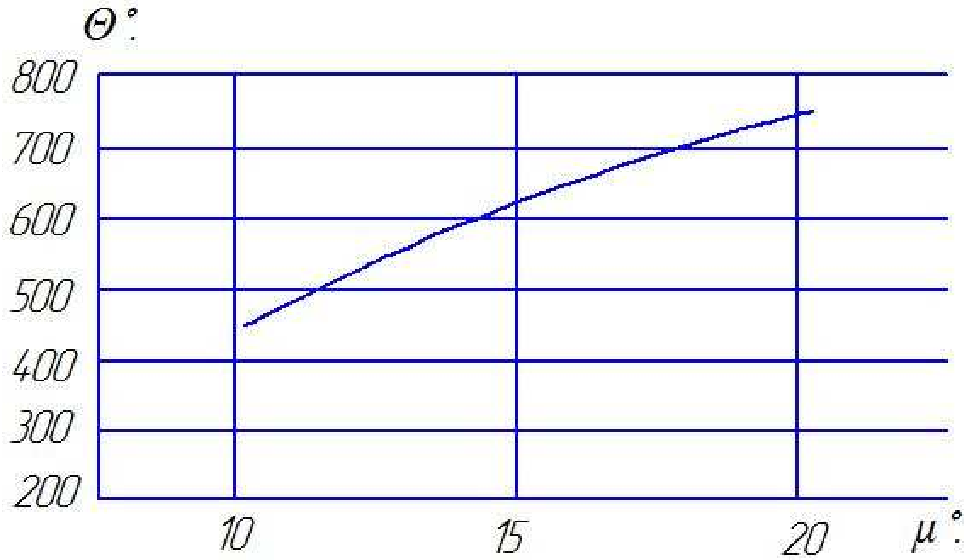

Figure 8

6. EXPERIMENTAL STUDY OF THE TEMPERATURE IN THE WORKPIECE WHEN COVERING MILLING

The results of experimental studies in determining the temperature of chips by calorimetric method found that at the stages of cutting and nursing its values are in the range of 410–460°C. When exceeding the permissible values of the blade wear chamfer (above 0,4 mm) and the tool speed of 12,000 min^{-1}, the chip temperature rises sharply up to the melting point of the processed material and is formed in the form of drops [5].

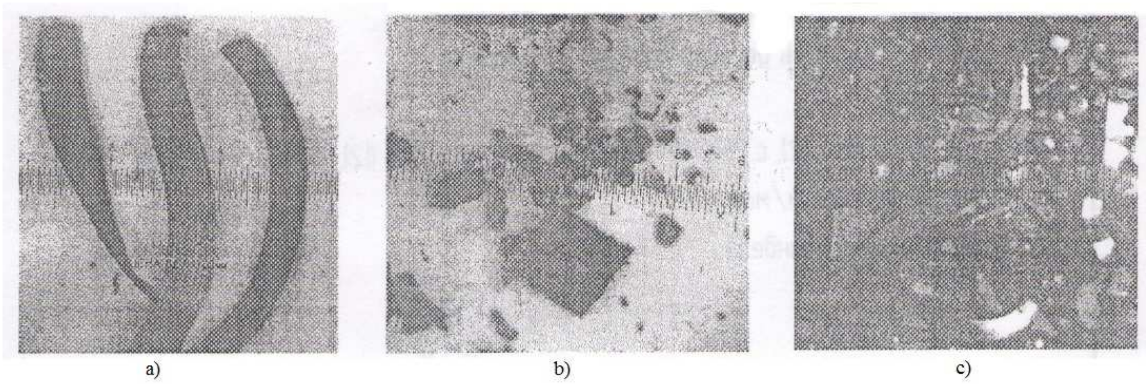

Figure 9. – a) at the stage of cutting; b) at the stage of nursing; c) when working a blunt tool and the tool rotation frequency of n_1=12,000 min^{-1}

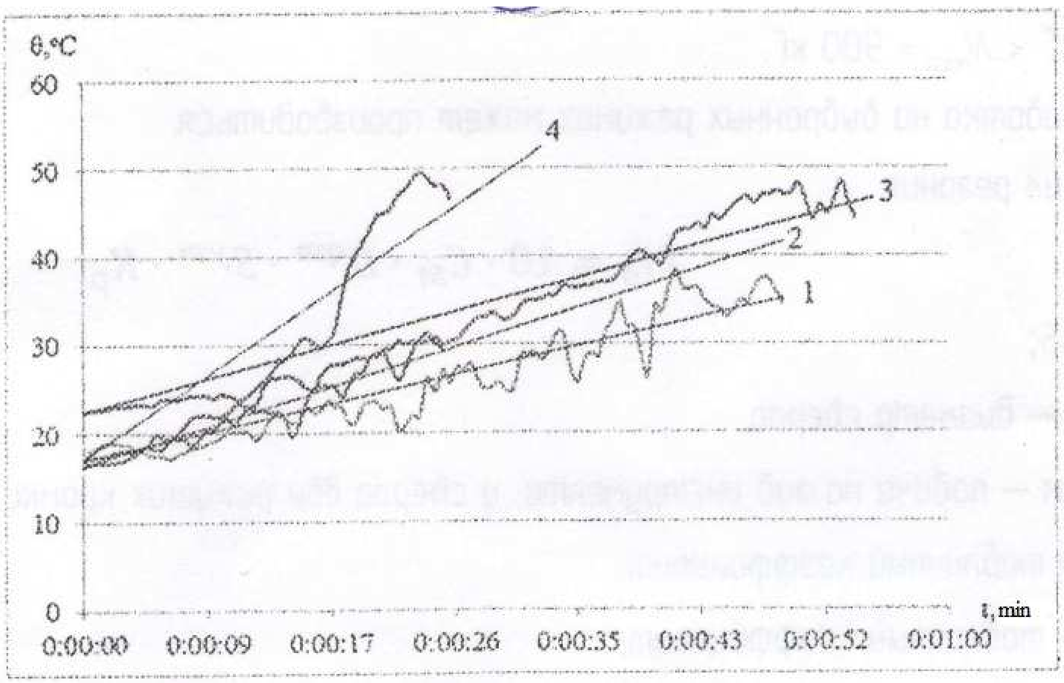

Figure 10. – The variation of the temperature of the workpiece surface with a diameter of 35 mm on the time of treatment with the frequency of rotation of the workpiece n_2 = 200 min^{-1}

The temperature of the part measured by the pyrometer varies depending on the rotation frequency of the tool and the workpiece and their diameters from 30 to 120°C. A typical graph of the part temperature change from the processing time is shown in figure 10.

1 – at tool speed n_1=3150 min^{-1} of cross feed S_c = 1,61 mm/min;

2 – at tool speed n_1=6300 min^{-1} of cross feed S_c = 2,25 mm/min;

3 – at tool speed n_1=9000 min^{-1} of cross feed S_c = 0,853 mm/min;

4 – at tool speed n_1=12000 min^{-1} of cross feed S_c = 1,543 mm/min.

As can be seen from the graphs, the higher the rotational speed, the higher the temperature value. The intensity of heat accumulation in the details is different and depends on the magnitude of the transverse feed - cutting depth. The greater the cross feed and less processing time, the lower the intensity of heat accumulation in the part by increasing the heat transfer into the chip.

As the wear chamfer increases on the back of the blade, the heat flows into the tool and the part increase, as evidenced by the increase in the heating temperature of the part to 120 degrees. At the same time, the influence of the transverse feed (cutting depth or section width of the cut layer), as a factor improving heat transfer into the chip, decreases.

Relatively low values of the heating temperature of the part (30–120°C) indicate that there are no significant structural and phase transformations in the surface layers of the part and the tool blade, which ensures high quality of the treated surface of the sphere.

In the study of tool blade wear, mechanical cutting and abrasive abrasion of irregularities on the blade surface with the formation of a wear chamfer of length l_{ch} and height h_{ch} along the auxiliary cutting edge and the adjacent back surface are observed. Moreover, the shape of the wear chamfer on the rear surface corresponds to the radius of the treated spherical surface.

Processing data of the measured value of blade wear showed that the permissible length and height of the wear chamfer is respectively l_{ch} = 2–4 mm and h_{ch} = 0,1–0,4 mm.

Conclusion

1. Considered the basic provisions of theoretical and experimental determination of heat and temperature in the processing of blanks cutting.

2. The obtained mathematical formulas for the calculation of the cutting temperature when machining with rotating tools.

3. The changes in the temperature of the part in time at different processing modes with embracing milling are experimentally established.

7. PROBLEM STATEMENT OF HEAT TRANSFER AND METHODOLOGICAL GUIDELINES FOR ITS IMPLEMENTATION

On a lathe model 16K20 grind a workpiece with a cutter plate made of hard alloy with predetermined angles φ and γ when the depth of cut *t* (mm) feed *S* (mm/Rev) and cutting speed υ (m/min).

To determine:

– power dissipation in the cutting zone Q (W);

– the equivalent conductivity of the tool holder with a cutting plate;

– the temperature on the reference plane of the cutting plate from the rear surface.

To make a conclusion about the possibility of weakening of the material holder, taking the softening temperature is 250 °C.

Before proceeding to solving the problem you should be familiar with the methods of calculating the thermal capacity of the cutting process [1] and study material related issues of the subject "Theory of cutting" [2–4].

Empirical formulas to calculate the cutting force using reference books for example [5].

To calculate the total thermal power [1, 2]. The result translated into the units of the international system.

To determine the equivalent thermal conductivity coefficient of the holder with the insert you can use the formula:

$$\lambda_e = \frac{H}{\dfrac{h}{\lambda_1} + \dfrac{H-h}{\lambda_2}},$$

where *h* – the height of the cutting plate, cm;

H – the height of the holder, cm;

λ_1 – the height of the holder, cm;

λ_2 – the thermal conductivity of the material of the holder, cal/cm·s·deg.

Values of λ are given in [1].

To calculate the temperature at the base of the insert, you can use the formula:

$$\theta = \frac{q}{\pi \cdot \lambda} \cdot (-E_i \cdot [-\frac{r^2}{4\omega \cdot \tau}]),$$

where *q* – the intensity of heat dissipation in the body of the cutter by a unit length of the cutting edge, cal/cm;

λ_1 – the thermal conductivity of the material of the insert, cal/cm deg;

r – distance from the cutting edge to the base plate rear surface, cm;

ω – the thermal diffusivity, cm^2/s;

$E_i(x)$ – the integral-exponential function;

τ – the integral-exponential function;

The intensity of heat dissipation in the body of the cutter is taken equal to 5% of the total amount of heat, i.e. $q = 0.05\ Q/b$, where b is the width of the cross section of the shear layer, cm; *Q* is the total quantity of heat cal/s.

The value of the integral-exponential functions, calculated by the approximate formula:

$$E_i(-x) = 0.5772 + \ln|x|,$$

The diameter and length of the detail necessary for determining treatment time to make their own.

7.1. Example

Task. On a lathe model 16K20 grind the workpiece of gray cast iron, HB220 cutter with a plate of hard alloy VK8 with a front angle $\gamma = 0^\circ$ and angle $\varphi = 60^\circ$. Cutting depth $t = 5$ mm, feed $s = 0{,}5$ mm/rev, cutting speed $\upsilon = 80$ m/min.

To determine:

– power dissipation in the cutting zone *Q*;

– the equivalent conductivity of the holder with the plate normal to the base of the cutter;

– to calculate the temperature on the reference surface of the plate of tool material from the back face, based on the assumption that the cutter is 5% of the total amount of heat.

The softening temperature is considered equal to 250 °C

1. The total amount of heat released during cutting can be determined by the formula [1]:

$$Q = 0{,}39 P_z \cdot \upsilon$$

where P_z – tangential component of the cutting force;

υ – cutting speed, m/min.

Component of the cutting force *Pz* can be calculated according to the formula [6]:

where C_p, x, y, n, K_p – correction factors

$$P_z = 10 \cdot C_p \cdot t^x \cdot S^y \cdot \upsilon^n \cdot K_p,$$

$$C_p = 92,\ x = 1,\ y = 0,75,\ n = 0$$

$$K_p = K_{mp} \cdot K_{\varphi p} \cdot K_{\alpha p} \cdot K_{\lambda p}$$

$$K_{mp} = (HB/190)^n = (220/190)^{1.25} = 1.2$$

$$K_{\varphi p} = 0,94,\ K_{\gamma p} = 1,1,\ K_{\lambda p} = 1,\ K_{\alpha p} = 1$$

$$K_p = 1,2 \cdot 0,94 \cdot 1,1 \cdot 1 \cdot 1 = 1,24$$

$$P_z = 10 \cdot 92 \cdot 5^1 \cdot 0,5^{0,75} \cdot 80° \cdot 1,24 = 3391\ \text{N}$$

In this case, the cutting area is allocated

$$Q = 0,039 \cdot 80 \cdot 340 = 106l\ \frac{\text{cal}}{\text{s}} = 4442\ \text{W}$$

2. To determine the equivalent thermal conductivity of the holder with the plate cutting part we can use the formula

$$\lambda_e = \frac{H}{\dfrac{h}{\lambda_1} + \dfrac{H-h}{\lambda_2}},$$

where h – the height of the plate, cm; take H = 4 mm = 0.4 cm;

H – height of the holder, cm; taken H = 25 mm = 2.5 cm;

λ_1 – the thermal conductivity of the material of the cutting plate; taken from Annex G for VK8 λ_1 = 0,13 cal/(cm·s·C°);

λ_2 – the thermal conductivity of the material of the holder; take from the app G for 40 steel λ_2 = 0,092 cal/(cm·s·C°);

Then

$$\lambda_e = \frac{2.5}{\dfrac{0.4}{0.13} + \dfrac{2.5-0.4}{0.092}} = 0.093\ \text{cal/cm} \cdot \text{s} \cdot \text{C}°$$

4. To calculate the temperature at the base plate you can use the formula

$$\theta = \frac{q}{\pi\lambda_1}\left(-E_i\left[-\frac{r^2}{4\omega r}\right]\right),$$

where q – the intensity of heat dissipation in the body of the cutter by a unit length of the cutting edge, cal/(cm·s·C°);

$E_i(x)$ – the integral-exponential function;

r – distance from the cutting edge to the reference plane of the plate, mm;

ω – the thermal diffusivity, cm^2/s;

τ – the processing time of one part, s;

The intensity of the heat dissipation q can be determined by the formula

$$q = \frac{0,05Q}{b}$$

where b – length of the active part cutting edge, cm:

$$b = \frac{t}{\sin\varphi} = \frac{5}{\sin 60°} = 5,76\ \text{mm} = 0,58\ \text{cm}$$

Then

$$q = 0,05 \cdot \frac{106l}{0,58} = 91\frac{\text{cal}}{\text{cm}} \cdot \text{s}$$

To determine the time of treatment we ask the length of the workpiece L = 25 mm and a diameter of 120 mm. In this case, the frequency of rotation of the parts will be equal

$$n = \frac{1000 \cdot \upsilon}{\pi D} = \frac{1000 \cdot 80}{3,14 \cdot 120} = 212\ \text{min}^{-1}.$$

The processing time of one part will be

$$\tau = \frac{L}{ns} = \frac{25}{212 \cdot 0,5} = 0,23\ \text{min} = 14\ \text{s}.$$

The thermal diffusivity taken from the app G are equal 0,246 cm^2/s.

The argument of the integral exponential function is equal to

$$-\frac{r^2}{4\omega\tau}=-\frac{0,8^2}{4\cdot 0,246\cdot 14}=-0,05,$$

but the function itself is equal to

$$-E_i(-0,11) = 2,3679.$$

The temperature at the base of the plate is equal to

$$\theta=\frac{q}{\pi\lambda_1}\left(-E_i\left[-\frac{r^2}{4\omega r}\right]\right)=\frac{91}{3,14\cdot 0,13}\cdot 2,3679=527°C.$$

Conclusion

The temperature on the base plate more than the temperature of softening of the material of the holder reduces the cutting conditions to apply the coolant.

CONCLUSION

In this manual in a brief and accessible form the physical basics of the theory of heat transfer, which allows students to study their characteristics in relation to the processing of cutting materials is described. Theoretical methods and formulas for determining the temperature are presented, a solution to the equation of heat conduction for metalworking is provided. The review of experimental methods of indirect and direct determination of temperature allows choosing the method most acceptable for these or those conditions of processing by cutting.

Example of theoretical analysis and experimental measurement of temperature in the mechanical processing of spherical surfaces of parts, as one of the most complex processes, clearly illustrates the technological capabilities of the implementation set out in this manual fundamental provisions and principles of heat transfer.

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CONTENT

Учебное издание

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машиностроительных специальностей
на английском языке

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