Provision Of The Quality Of Manufacturing Gear Wheels In Energy Engineering

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Abstract. The technique of calculation of internal residual stresses arising during grinding of wheels from cemented steels is offered. On the basis of performed calculations and experiments, ways of improving the quality of manufacturing of work surfaces of gear gears, which are used in aggregates of thermal and nuclear power plants, are proposed and substantiated.

Keywords: cemented layer, residual stresses, solid lubricant, intermittent circle.

1 Introduction

The development of modern power machine engineering goes along the line of continuous increase of speeds, efficiency and power of aggregates. In all cases, when the optimum engine speed is significantly different from the speed of the actuator, a gear reducer is used. Gear transmissions and gearboxes are responsible parts of modern mechanisms and occupy an important place in the domestic power engineering industry. Strength and wear resistance of gears, in addition to design factors, largely depends on the processing techniques. Heavy-loaded cogwheels are made from cemented chromium-nickel and chromium-nickel-tungsten steels 12XH3A, 12X2H4A, 20X2H4A and 18X2H4MBA. The final stage of manufacturing of such wheels is the operation of gear grinding. In the process of teeth-grinding in a thin surface layer, complex thermomechanical processes can occur. As a result of short-term heating to high temperatures in the surface layer the phase and structural transformations occure, called burns, and in some cases even micro and macro-trunks. In addition, there are cases of manufacturing gears with hidden grinding defects (for example, the appearance of large tensile stresses in the surface layer of the tooth), which reduces the service life, and in some cases causes tooth failure under operating conditions. The development of effective measures to ensure the quality of the surface layer in the operation of gear grinding largely depends on the possibility of predicting (or calculating) temperatures and residual stresses over the depth of the cemented layer of teeth.

2 Analysis of the latest publications

Problems of mathematical modeling of the thermal and stress-strain state of the material of a part during grinding are discussed in [1-2]. The problems of analytical determination of the values of tensile residual stresses taking into account the heterogeneity of the carbon content in the cemented layer have not been given sufficient attention. The reasons for the formation of surface burns and cracks in the grinding of cemented gears are also analyzed. The harmful effects of grinding are suggested to be reduced by optimizing the parameters of the cutting regime, and the problems of forming the stress-strain state of the surface layer during abrasive processing are considered mainly from the qualitative point of view or are devoted to the experimental study of residual stresses.

The results of mathematical modeling of thermal fields during grinding are shown in [2], but there are no questions of the reason for the appearance of temperature and the change in its values depending on the grinding parameters.

In [3], questions of internal transformations of martensite-nesting steels under different heating conditions are considered, however, the transformations at surface heating, which takes place during grinding, are not illuminated.

In [4], the results of creep tests of martensitic-aging steel are cited for prolonged heating, which also does not correspond to the conditions of heating during grinding.

The sources [5] deal with the effect of alloying elements on the hardening processes of martensitic aging steels, but it is practically impossible to correlate the results with the heating conditions during grinding.

The problems of structural heredity and the conditions for the release of dispersed intermetallic particles from a solid solution under the effect of temperature are considered in [6], which also does not explain the behavior of these steels when heated by grinding.

The results of studies on the change in the strength properties of martensitic-aging steels as a result of structural changes, which, in turn, are the results of temperature changes, are presented in [7]. Despite the interesting data, these materials can not be used to predict the behavior of these steels when they are heated by the grinding temperature, since in the sources under consideration the heating is volumetric and long, and in the case of grinding, there is a surface and short-term heating.

Thus, by analyzing the data available in the literature, it can be concluded that the behavior of steels is sufficiently well covered when the operating temperature is changed. Practically there is no data on how the characteristics of steels and alloys change after exposure to a grinding temperature, the values of which can be higher than the operating temperatures.

3 An objective

To develop a procedure for calculating temperatures and residual stresses at different levels of the cemented layer that arise during Teeth grinding, and to suggest ways to improve the thermal and stress-strain state of the surface layer of the teeth in abrasive processing.

4 Methods of research

Mathematical modeling of thermal processes during grinding, modeling of the process of formation of residual stresses and cracks, modeling of the oscillation system when grinding with a tearing circle.

5 Statement of the main material

In the surface layers of cemented parts during grinding, stresses of a different magnitude and sign are formed. Residual stresses arise as a result of the interaction of plastically and elastically deformed layers. If the plastically deformed layers after cooling tend to increase their length in comparison with the initial one, then the elastic-deformed layers tend to return to the original length. Consequently, some layers will experience compressive stresses, while others will stretch. These stresses remain in the part after grinding and are therefore called residual. The main danger in grinding is the occurrence of residual tensile stresses of considerable magnitude, which can lead to cracking of the surface cemented layer. The cause of the occurrence of residual stresses during grinding with an unchanged phase-structural composition of the cemented layer is the grinding temperature, which leads to uneven thermal expansion of its individual microlayers, which causes the formation of residual stresses. In addition, it should be borne in mind that in the phase and structural transformations, additional causes for the formation of residual stresses are created because the density of each phase and structure formed is different.

When calculating the grinding temperatures, two things must be taken into account:

1. The intensity of the heat flow is unevenly distributed over the contact spot of the grinding wheel with the workpiece. At the beginning of the trajectory of the cutting grain passing through the material being treated, the intensity of the thermal current is smaller, and at the end of the trajectory, where the cross section of the chip is maximal, it is higher. Thus, it is necessary to determine the temperature of the cutting surface, taking into account the heat flux density, which is unevenly distributed over the contact spot of the grinding wheel with the metal.
2. It is of practical interest to know the temperatures that arise not only on the cutting surface (that is, on the surface where the chips are currently being formed), but also on the machined surface located below the cutting surface. In addition, to calculate the thermal residual stresses, it is necessary to know how the temperatures are distributed deep into the cemented layer.

To solve the first problem, we choose a coordinate system X, Y, Z on the surface of a semi-infinite body. Let us agree that heat is supplied to a certain region bounded by a rectangle whose sides are parallel to the X and Y axes:

$$-a \le x \le a\ ,\ -b \le y \le b\ , \tag{1}$$

where $a = \frac{\sqrt{D_w \cdot t}}{2}$, $b = \frac{S}{2}$, D_w – diameter of grinding wheel, t- depth of grinding, S- transverse feed. Outside this region, there is no heat flow through the surface of the part. The heat source is assumed to be immovable, and the surface of the workpiece is moving with the velocity V_p in the direction of decrease of the coordinate.

Let us consider the steady-state thermal regime when $\tau \to \infty$. For an elementary area with a center with coordinates, the distribution of temperatures is described by the dependence [9]:

$$T_1(z) = \frac{q(x)}{2\pi\lambda_1} \cdot \frac{1}{R} \exp\left(-\frac{V_\partial \cdot r + V_\partial \cdot (x_0 - x)}{2a_1\tau} \right) \tag{2}$$

Where T_1 is the temperature at the cutting surface, ° C; *x,y,z* - current coordinates of the position of the part, m; q(x) - the specific intensity of the heat flux at a given point of the contact spot of the grinding wheel with the workpiece, Bt / m^2; λ_1 - coefficient of thermal conductivity of the cutting surface, W / m · °C; $R = \sqrt{(x_0 - x)^2 + (y_0 - y)^2 + z^2}$ - radius-vector of coordinates; V_p - speed of moving parts relative to a fixed thermal source, m / min; τ- the moment of time, s; x_o- coordinate at time τ_0 , m; r- radius of curvature of the cutting grain, m; a_1 - coefficient of thermal diffusivity of the cutting surface, m^2 / s.

Integrating expression (2) over the region D , we obtain:

$$T_1(z) = \frac{1}{2\pi\lambda_1} \int_{-a}^{+a} q(x)dx \int_{-b}^{+b} dy \left\{ \frac{1}{R} \cdot \exp\left[-\frac{\mathbf{V}_{\text{д}} r + \mathbf{V}_{\text{д}} (x_0 - x)}{2a_1\tau} \right] \right\} \tag{3}$$

Where *a,b* is the half-width and half-length of the contact spot of the circle with the detail, m.

In order to solve the second problem, that is, to bring the temperature on the surface to the temperature of the worked surface, it can be imagined that a certain body, heated to temperature T_1 and consisting of the material of the part, abrasive grains and the bundle of the circle, moves along this surface. Each point of the treated surface is in contact with this body for a period of time $\tau = \frac{\sqrt{D_w \cdot t}}{Vp}$.

To simplify the problem, it can be imagined that two semi-bounded bodies with heat-insulated lateral surfaces are brought into contact with each other at the initial moment of time τ0 the temperature of the first body is equal to the surface temperature of the cutting surface, and the temperature of the second body is equal to the temperature of the treated surface T2. It is necessary to find the temperature of the second body at times from τ=0 , to $\tau = \frac{\sqrt{Dw \cdot t}}{V_p}$. Fig.1

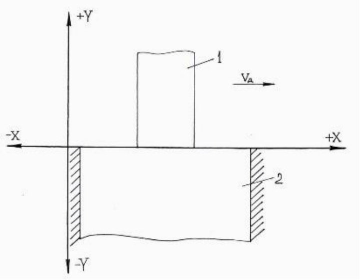

Fig. 1.

Thus, the problem reduces to solving the heat equation under boundary conditions of the fourth kind, which corresponds to the contact of two solids with different temperatures.

The solution of this problem is given in the source [10]. Using this data, we have

$$T_2(z,\tau) = \frac{T_{01}\varepsilon_1}{\varepsilon_2 + \varepsilon_1}\left(1 - erf\,\frac{|z|}{2\sqrt{a_2\tau}}\right) \tag{4}$$

where $T_{01} = T_1$ is the temperature at the cutting surface, ° C.

Thus, considering the temperature at the cutting surface (2), the grinding temperature $T_2(z,\tau)$ applied to the treated surface, taking into account that the power of the heat source is unevenly distributed over the contact spot of the grinding wheel with the workpiece, and the thermal power at a given point of the contact spot depends on the certain coordinate x is:

$$T_2(z,\tau) = \frac{\varepsilon_1 \cdot \int\limits_{-a}^{+a} q(x)dx \int\limits_{-b}^{+b} dy \left\{\frac{1}{R}\cdot \exp\left[-\frac{\mathrm{V}_{\text{д}} r + \mathrm{V}_{\text{д}}(x_0 - x)}{2a_1\tau}\right]\right\}}{2\pi\lambda_1(\varepsilon_2 + \varepsilon_1)}\left(1 - erf\,\frac{z}{2\sqrt{a_2\tau}}\right) \tag{5}$$

Where $\varepsilon_1, \varepsilon_2$ - the coefficients of thermal activity, respectively, of the thermal source and the treated surface, $\varepsilon = \sqrt{\lambda c \gamma}$ $\cdot 10^3$ J / $m^{2\cdot 0}C \cdot s^{0.5}$, λ-coefficient of thermal conductivity j / m $\cdot$ $^0C\cdot$ s, *c* - specific heat-J / kg ^0C, γ-density-kg / m^3

The values of the residual stresses arising at different levels of the cemented layer can be determined using the expression:

$$G_2(z) = \frac{E_2\alpha_2\varepsilon_1 \int\limits_{-a}^{+a} q(x)dx \left\{\frac{1}{R}\cdot \exp\left[-\frac{V_\partial^{\,2} r + V_\partial^{\,2}(x_0 - x)}{2\cdot a_1\cdot\sqrt{D_{kp}\cdot t}}\right]\right\}\left(1 - erf\,\frac{z\cdot\sqrt{V_\partial}}{2\sqrt{a_2\sqrt{D_{kp}\cdot t}}}\right)}{(2 - 2\cdot\mu_2)\cdot 2\pi\lambda_1(\varepsilon_2 + \varepsilon_1)} \tag{6}$$

where E_2 is the modulus of elasticity of the cemented layer, Mpa; α_2 linear coefficient of thermal expansion of the cemented layer, 1 / ºC; μ_2 Poisson's coefficient of the cemented layer.

The values of the power of the heat source which is necessary both for solving the temperature problem and for solving the problem of determining residual stresses can be determined from the source, depending on the processing modes

Figure 2 shows the calculated curves describing the distribution of internal residual stresses over the depth of the cemented layer after grinding 18X2H4BA steel with cutting depths of $t = 0{,}1$ mm (without cooling) and $t = 0{,}015$ mm (with cooling).

The cemented layer consists of three zones [11] - the hypereutectoid zone, with a carbon content of up to 1.2%, a eutectoid zone with a carbon content

0.8%, a pre-eutectoid zone with a carbon content of 0.3-0.7%. The thermophysical characteristics vary slightly depending on the carbon content and doping.

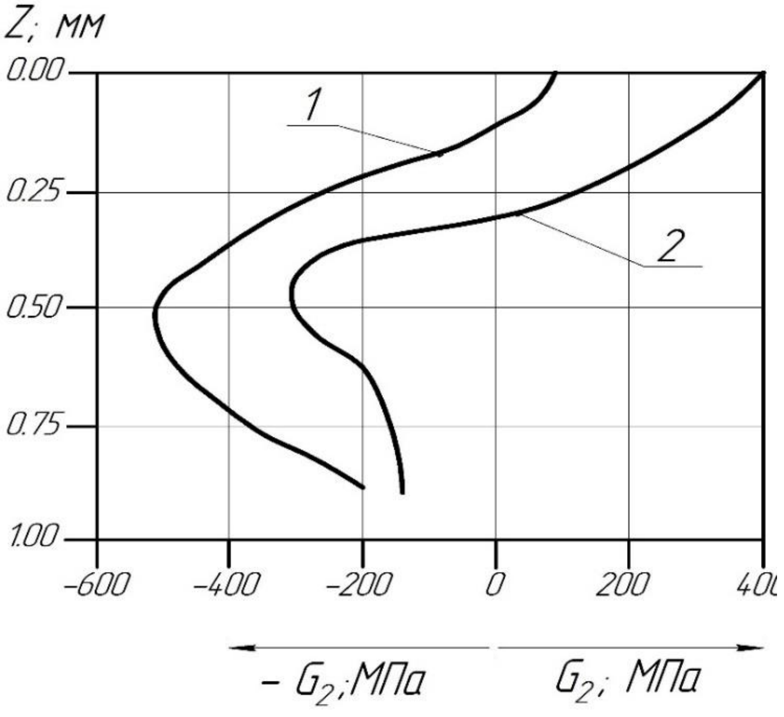

Fig. 2. Distribution of internal residual stresses in the depth of the cemented bed for two grinding modes: $t = 0{,}015$ mm and $t = 0{,}1$ mm

As the distance from the surface increases, the tensile stresses decrease and become compressive. When grinding according to the most severe regime (curve 2), the compressive stresses are obtained as the least. The appearance of tensile stresses during the grinding of gears leads to a decrease in their fatigue strength.

The calculation of internal residual stresses was carried out taking into account the change in the thermophysical characteristics in the zones of carburization. The appearance of grinding cracks is facilitated not only by the residual, but also by the time tensile stresses that arise during grinding upon cooling to the temperatures at the onset of the martensitic transformation [8]. The cause of crack formation are high contact temperatures and temperature gradient in the cutting zone, as well as high cooling rates of the treated surface after it leaves the contact zone with the abrasive wheel.

To reduce internal tensile stresses and the likelihood of crack formation, it is necessary to reduce the temperature in the cutting zone and the cooling rate by all available means [8]. This can be achieved with the use of various lubricating-cooling agents, solid lubricants and pastes.

6 Discussion

Most often, thermal grinding defects are formed in cementitious, improved high-carbon steels, low- and medium-alloyed, with a martensite structure or tempered martensite. With rapid heating by the grinding temperature of the surface of the grinded part of the hardened steel above the Ac_1 line, the martensitic structure of the surface layer transforms into an austenitic structure, that is, an inverse martensitic transformation takes place. This transformation is all the more facilitated by the fact that as a result of the high specific pressures exerted by the abrasive grains on the surface of the metal, the point Ac_1 may decreases to lower temperatures.

After a rapid heating of the surface layer, rapid cooling follows with rates significantly exceeding the critical quenching rates. The points Mk for these steels are mostly below 20 ° C, that is, at the same temperature, to which the metal cools during grinding. As a result, the martensitic transformations do not take place completely, as a result of which a structure of austenite of the secondary quenching is fixed in the surface layer, resulting in the name of the grinding burn of quenching.

The final cooling of the austenite structure takes place at a temperature interval of 20 ° C and lower. The cooling process ends between points Mn and Mk. The temperature interval until the end of the martensitic transformation does not overlap, which causes incompleteness of this transformation and fixation of a significant part of the austenite.

Phase - structural changes in the surface layer of hardened steel during grinding are called grinding burns. Burns are caused by high residual stresses and cracks in the surface layer, a decrease in the wear resistance of the ground surface. This reduces the strength, reliability and durability of the ground surface, and, consequently, of the entire part.

To reduce internal tensile stresses and the likelihood of crack formation, it is necessary to reduce the temperature in the cutting zone and the cooling rate by all available measures.

7 Conclusions.

A technique is proposed for calculating the internal residual stresses arising when gears are grinded from cemented steels.

Based on the performed calculations and experiments, ways to improve the quality of manufacturing the working surfaces of tooth gears used in thermal and nuclear power plants are proposed and justified.

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