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CALCULATION OF CALIBRATION FORCE OF GEAR TEETH BY EXPANDING WITH CONE-SHAPED PUNCH

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S u m m a r y . The technology of producing gear-wheels by stamping with division of operations of rough and finishing forming is examined. A solution for stress and deforming force of calibration of gear teeth in a stamp with cone-shaped punch is found.
K e y w o r d s *:* gear-wheels, calibration, stamping, deforming effort, tensions.

INTRODUCTION

Stamping tooth gear-wheels is an effective technology, which allows to decrease the consumption of metal and power, labour-intensive characteristics, and to increase operating abilities of items. [15]

RESEACH OBJECT

The research introduces the technology of producing tooth-wheels with division of operations of rough forming and finishing forming. In this case the level of final deformation is low, deformation occurs in cold conditions and a finishing operation is calibration, i.e. high precision of teeth geometrical dimensions is reached. The rough work-piece for calibration can be a half-way product with not completely shaped teeth, made either by cold, hot or warm stamping, or of powder metal by pressing and sintering. [18]

Calibration is performed in a special stamp. The rough work-piece for calibration is made in the shape to enter the cavity of calibration stamp with a gap which allows free entrance. Its surface and the stamp surface are covered with technological lubricant (for example, machine grease with molybdenum disulfide). The deformation level at the operation of calibration, calculated according to the change of a tooth depth, does not exceed 5…10%, that allows to provide 8-9 level of precision of tooth wheel dimensions and roughness R_a=0,32. [17-20]

REZULTS OF EXPERIMENTAL RESEARCH

In the technology under investigation the calibration operation is exercised according to the scheme of deformation of teeth with radial flow of metal, performed with a cone-shaped punch, which expands the center bore of a tooth gear and makes the metal flow in a radial direction. While developing the technological process and tooling, it is necessary to distinguish operating stress in a stamp and the level of max. deforming force at the final stage of calibration which corresponds the complete formation of teeth. [9,10]

The design model of calibration of gear teeth with radial flow of metal is shown in fig.1. The amount of metal under deformation is presented consisting of two areas. In Area I there is metal flow in a tooth, Area II constitutes a ring with a conical bore situated under internal (on the side of a punch) and external (on the side of a tooth) pressure. To develop calculating formulas we apply the method of simultaneous solution of equilibrium and plasticity equations.

Due to the fact that the length of a tooth is rather more than its depth, the flow of metal in the direction of the length is negligibly small. So, without making a raw error, we can take that in Area I metal is situated in conditions of flat deformation.

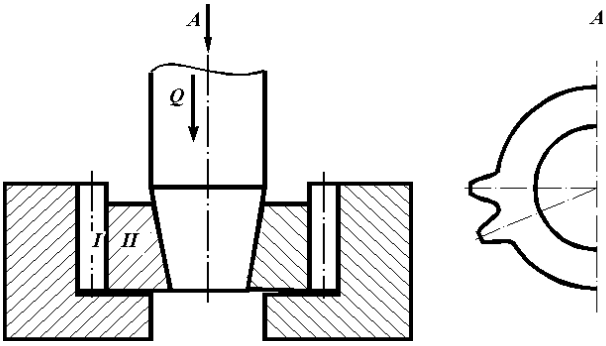

Fig. 1. The scheme of calibration of gear teeth with radial flow of metal

For the analysis we divide the space of Area I to the finite number m of elementary units, changing their curved configuration to linear wedge one (fig.2).

The size of blocks h_j, h_{j+1}, α_j is calculated using the equations of the lines of gearing for their given number m.

The stress in the deformed metal while entering the tooth hole is calculated using the approximate equations of equilibrium and plasticity that for the flat plastic flow of wedge elementary units in polar coordinates r and ρ is as follows [1]

$$\frac{d\sigma_r}{dh_r} + \frac{(\sigma_r - \sigma_\varphi)}{h_r} + \frac{2\tau_k}{\alpha h_r} = 0, \quad (1)$$

where: $\tau_k = \mu 2k$ - value of shear stress on a contact surface;

$k = \sigma_s / \sqrt{3}$ - constant plasticity,

μ - coefficient of contact friction.

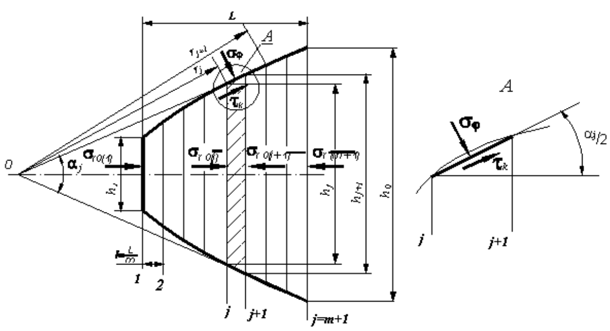

Fig. 2. Calculating scheme for Area I with dividing it to the finite number of elementary units

Integrating the equation (1) with definition of the constant of integration from the condition that on the left edge of elementary wedge unit with $h_r = h_j$, normal stresses are $\sigma_r = \sigma_{r0(j)}$, we have

$$\sigma_{rj} = -2k\left(1 + \frac{2\mu}{\alpha}\right) ln\frac{h_r}{h_j} + \sigma_{r0(j)}, \quad (2)$$

where: j- section size.

Calculation of the normal stress on the boundary of Area I and Area II $\sigma_{r(m+1)}$ using the formula (2) is performed by numerical method in sequence, starting with the second section from the left boundary of Area I. In this connection, for the free flow of metal in a tooth hole we take the value $\sigma_{r0(1)} = 0$, and for the final stage, when the formation of angles is performed - $\sigma_{r0(1)} = 4k$.

Strengthening of metal while forming the teeth is calculated by taking the average values of the constants of plasticity in elementary units

$$k_{cp} = \frac{k_j + k_{j+1}}{2},$$

$$k_j = \frac{1}{\sqrt{3}}\left[\sigma_{s0} + A\left(\frac{h_0 - h_j}{h_0}\cdot 100\right)^n\right], \quad (3)$$

where: σ_{s0}, A, n - initial flow stress and coefficients of linear approximation of strengthening curve [2].

Area II is a ring, limited with radial surface passing through the bottom line of teeth and the cone-shape surface of punch. At the final stage of calibration the length of circular fiber in Area II hardly changes because the flow of metal in the hole under the tooth is negligible. Hence, we can take it that at the final stage of calibration in the sections of circular Area II flat deformed condition takes place.

In Area II of stress we find from simultaneous solution of differential equilibrium and plasticity equations. Usage of shear stress law allows to get a closed solution, when the arbitrary functions in coordinates r and θ are got from the plasticity equations with the following calculation of integration constant from conditions of equation of stresses at the boundary of Area I and Area II.

$$\sigma_\theta = 2k\left(\frac{2\mu}{\beta} + \sqrt{1 - 4\mu^2}\right) ln\frac{r}{r_a} + \sigma_{r(m+1)}, \quad (4)$$

$$\sigma_r = -2k\left[\left(\frac{2\mu}{\beta} + \sqrt{1 - 4\mu^2}\right) ln\frac{r}{r_a} - \sqrt{1 - \frac{4\mu\theta}{\beta}}\right] + \sigma_{r(m+1)}.$$

The value of axial deforming force transmitting through the punch we can find by taking the value of the projections of all forces on a vertical axis.

$$Q = \iint_S |\sigma_s| \sin\beta dS + \iint_S |\tau_k| \cos\beta dS \ . \qquad (5)$$

The final formula for the stress of gear tooth calibration is as follows

$$Q = 2\pi d_c \left[\left(\frac{2\mu}{\beta} + \sqrt{1-4\mu^2} \right) \left(2{,}3 b_2 \ln\frac{b_2}{b_1} - b_2 + b_1 \right) + \mu H + \frac{\sigma_{r(m+1)}}{2k}(b_2 - b_1) \right] \qquad (6)$$

Calculation of the stresses on the boundary of Area I and Area II is performed by a numerical method, here the accuracy depends on the number of divisions m.

Experimental proof of the solution received for strengthening the calibration of a tooth-gear of a starter's reduction unit was performed, the work-piece for it was a half-way product, made of iron powder and sintered. The experiment proved a good fit of design data, deviation rate is 15%. [21]

CONCLUSIONS

The analysis of stressed-deformed conditions during calibration of gear teeth with radial flow of metal is carried out. By means of simultaneous solution of differential equilibrium and plasticity equations we got the formula for deforming force, necessary for calibration of teeth by cone-shaped punch.

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РАСЧЕТ УСИЛИЯ КАЛИБРОВКИ ЗУБЬЕВ ШЕСТЕРНИ РАЗДАЧЕЙ КОНИЧЕСКИМ ПУАНСОНОМ

Марина Морнева, Владимир Гаврыш, Наталия Кузьменко

Аннотация. Рассматривается технология изготовления зубчатых колес штамповкой с разделением операций предварительного и окончательного формообразования. Получено решение для напряжений и деформирующего усилия операции калибровки зубьев шестерни в штампе коническим пуансоном.

Ключевые слова: зубчатые колеса, калибровка, штамповка, деформирующее усилие, напряжения.