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INFLUENCE OF WORKPIECE RUN OUT ON CHANGE OF RADIAL CUTTING FORCE IN A CYLINDRICAL GRINDING

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The workpiece run out at its grinding on cylindrical grinder influents on grinding wheel wear and stability of grinding. This paper is intended for analysis of instantaneous change of cutting force at every revolution of the running out workpiece. The cutting force increase is evaluated by the rate of the instantaneous cutting force and stabile force at cutting with a constant allowance.

At analysis of workpiece grinding on a cylindrical grinders researchers the run out evaluated as a static factor which depending on allowance variation changes the grinding force strait proportional to change allowance value and in dependence on rigidity of a technological system either increasing the form error of the workpiece or grinding time necessary to correct the form accuracy [1, 2]. The notice was not fixed that the form error can act as a factor sharply changing the grinding force not straight proportional to change of allowance but in a greater degree. Wear of a grinding wheel and especially its waviness propagation may markedly increase. Grinding stability decreases.

The cross section form error of the workpiece being ground may be different, but at use of turned blanks the biggest value has the run out associated with eccentricity of the turned cylindrical surface of the blank and center marks of the piece. We shall not analyze the reasons of it, but it is possible to say that the run out can achieve tenths parts of mm. The phenomenon of grinding such eccentric parts is analyzed in this article. We in this paper did not set task to analyze in full the dynamics of response of a technological system on a stepped force increase, but only to show the problem of the phenomenon.

At grinding with constant allowance the grinding force falling to a width unit of the grinding wheel is straight proportional to product of allowance value u and workpiece revolving speed V_w. Because V_w is equal to product of piece radius R and revolving frequency ω, radial force F_y falling to width unit of the grinding wheel is equal

$$F_y = \omega \cdot R \cdot u \cdot 1 \cdot k_w, \tag{1}$$

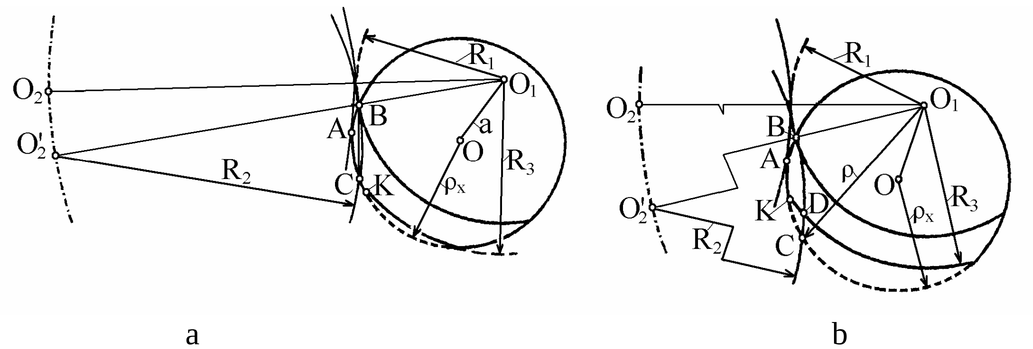
there k_w is coefficient of the grinding force N/(mm^3/s) [3, 4].

In our work [5] it was shown that the product of right side of equation (1) $\omega \cdot R \cdot u \cdot 1$ can be kept as the time derivative of grinding volume *dW/dt* falling to width unit of the grinding wheel. In our case instead of *dW/dt* we shall take $\Delta W/\Delta t$, so the instantaneous grinding force can be calculated by equation

$$F_y = \Delta W \frac{1}{\Delta t} k_w, \tag{2}$$

Because the width unit is constant, it is possible to search not the derivative of grinding volume, but the area of allowance being fed for grinding. It is possible to analyze the change in time the product $\omega \cdot R \cdot u$ and on the ground of it to evaluate the value of instantaneous force at cutting of a grinding wheel into the piece running out.

Fig. 1 shows two cases of cutting of a wheel into the round blank with radius ρ_x which center point O does not coincide with rotation center O_1. Eccentricity of the blank is a. At previous turn the wheel had ground a section of the blank surface by radius R_3. The new radius being formed is R_1. At cutting into the blank at case Fig. 1 a the wheel at the beginning touches the blank at point A and after that cuts into it by an arc till reaching point B on an arc with radius R_1 and point C on the blank surface with radius ρ_x. Wheel radius is R_2. Further the grinding runs with some allowance increase till point K and after that the grinding occurs with constant depth of cut. At the case Fig. 1 b the wheel after touching the blank at some point A cuts into it by an arc with radius R_2 till reaching point B on radius R_1 and intersects with radius R_3 in point D. Infeed till this moment is increased because it depends on run out of the blank and its revolution round axis. After this moment the grinding runs with constant allowance.



a b

Fig. 1. Schemes of cutting of a wheel into the blank: a – at contact point B wheel cuts only sector BAC; b – wheel cuts sector BAKD

It is possible to show that at the moment, when the grinding wheel cuts into the workpiece, the instantaneous grinding force may increase heavily in comparison with the grinding with constant allowance, and may exceed its value several times. Exceeding rate η can be expressed by equation

$$\eta = \Delta A_x /(\Delta t\omega R_1 u), \tag{3}$$

where ΔA_x is the area of a blank cross-section (perpendicular to its axis) being fed to cut off in stretch of time Δt; ω is the rotation frequency of the blank in centre pins; R_1 is radius of the blank, which is got at the turn, being investigated; u is the constant allowance being cut off from the blank in grinding with constant allowance. $\Delta A_x / \Delta t$ for Fig. 1 a is change in time of area of section limited by two radiuses ρ_x and R_2. For Fig. 1 b it is change in time of the area limited by radiuses ρ_x, R_2, and R_3.

Area A_x in Fig. 1 a can be expressed by equation

$$A_x = \frac{2}{3} l_x(\rho_x + R_2 - \rho_3) \tag{4}$$

where
$$l_x = \frac{1}{\rho_3}\sqrt{(R_2^2 - (\rho_3 - \rho_x)^2)((\rho_3 + \rho_x)^2 - R_2^2)}; \tag{5}$$

$$\rho_3 = \sqrt{(R_1 + R_2)^2 + a^2 - 2(R_1 + R_2)a\cos\left[arccos\left[\frac{(R_1 + R_2)^2 + a^2 - (R_2 + \rho_x)^2}{2(R_1 + R_2)a} - \omega t_x\right]\right]}. \tag{6}$$

There l_x is length of chord BC, ρ_3 is distance from blank center O to center O_2 of a grinding wheel, ω is revolving frequency of the blank, t_x is time from grinding wheel touches a blank at point A till the analyzed moment. Area ΔA_x is evaluated as change of area A_x by time moment Δt. For Fig. 1 b area A_x is equal to area of sector limited by radiuses ρ_x and R_2 minus area of sector KDC. The first of them is calculated by equations (4)-(6), the second is expressed by equation

$$A_{KDC} = \sqrt{p(p-b)(p-c)(p-d)}, \tag{7}$$

where $b=KC$, $c=KD$, $d=CD$ (see Fig. 1 b);

$$p = (b+c+d)/2;\; b = \sqrt{R_3^2 + \rho^2 - 2R_3\rho\ \cos\psi_A};\; c = R_3\sqrt{2(1-\cos\psi_B)}, \tag{8}$$

$$d = \sqrt{R_3^2 + \rho^2 - 2R_3\rho\ \cos(\psi_A - \psi_B)}, \tag{9}$$

$$\psi_A = arccos\frac{(R_1 + R_2)^2 + \rho^2 - R_2^2}{2(R_1 + R_2)\rho} - arccos\frac{(R_1 + R_2)^2 + R_3^2 - R_2^2}{2(R_1 + R_2)R_2}; \tag{10}$$

$$\begin{aligned}\psi_B = \omega t_x - arccos\frac{(R_1 + R_2)^2 + a^2 - (R_2 + \rho_x)^2}{2\cdot(R_1 + R_2)\cdot a} + \\ + arccos\frac{(R_1 + R_2)^2 + R_3^2 - R_2^2}{2(R_1 + R_2)R_3} + arccos\frac{R_3^2 + a^2 - \rho_x^2}{2R_3 a};\end{aligned} \tag{11}$$

$$\rho = \sqrt{\rho_x^2 + a^2 - 2\rho_x a\cos\left[arccos\frac{a^2 + \rho_3^2 - (R_1 + R_2)^2}{a\rho_3} + arccos\frac{\rho_3^2 + \rho_x^2 - R_2^2}{2\rho_3\rho_x}\right]}. \tag{12}$$

Radius R_1, it is the radius at which the blank will be ground, so the radius R_3 at every revolution of the blank will change. For this reason will be different angle α between the line connecting axes of a grinding wheel and revolution axis O_1 of the blank and eccentricity line a at the moment when grinding wheel will touch the blank at point A. This angle is defined by equation

$$\alpha = arccos\frac{(R_1 + R_2)^2 + a^2 - (R_2 + \rho_x)^2}{2 \cdot (R_1 + R_2) \cdot a}. \qquad (13)$$

After time t_c the wheel will touch point B on a blank and intersect with its radius ρ_x in point C. Angle α will change up to value

$$\alpha - \omega t_C = arccos\frac{R_1^2 + a^2 - \rho_x^2}{2 \cdot (R_1 + R_2) \cdot a}. \qquad (14)$$

Values a, R_1, R_2, ρ_x, u and ω are known, so by equations (4) – (14) it is possible to define area A_x and A_{KDC} and time t_c for every revolution of the blank and at division of time t_c to intervals Δt from equation (3) to define value η for every revolution and every time interval.

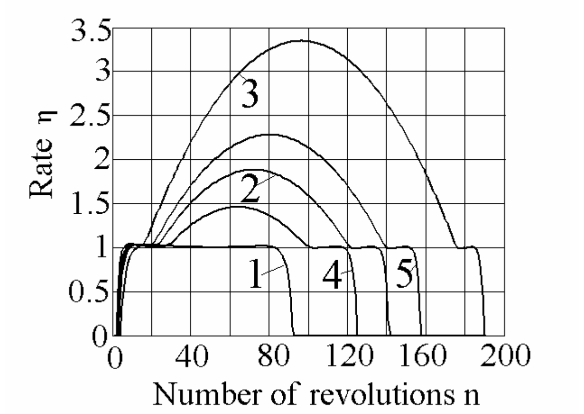


Fig. 2. Dependence of rate η on diameter and run out of the blank: 1 – 3 - diameter o20, 4, 5- diameter o30; run out (mm): 1- 0.1, 2- 0.15, 3 - 0.2, 4 – 0.2, 5 – 0.25

Fig. 2 shows dependence of rate η on eccentricity a of the blank ground by the wheel with diameter o500 mm and workpiece rotation speed 30 m/min at grinding of blanks with diameter o20 and o30 mm. Infeed rate at all cases is 1 mm/min. Time interval Δt in these calculations was got $\Delta t = t_c /3$. It is seen that at increase of run out rate η increases. It was also find that at decrease of rotation speed of the blank rate η decreases.

Conclusion: In a result of workpiece run out at cylindrical grinding the grinding force increases not straight proportional to change of allowance, but in a greater degree. Theoretical analysis made in this paper enables to calculate the rate of its increase in comparison with grinding with constant allowance without run out.

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