Modeling of an equal-wear shape of grinding wheel when working with longitudinal feed

D P Salova¹, N V Nosov²*, and P M Salov¹
¹Chuvash State University, Cheboksary, Russian Federation
²Samara State Technical University, Russian Federation

*nosov_nv@samgtu.ru

Abstract. The paper proposes a model of an equal-wear shape of the working surface of grinding wheels operating in the self-sharpening mode, where the principles of system workability are used. It is established that to obtain engineering solutions, the wheel should be considered as a ceramic body that cuts into the ‘Voicht medium’. A disadvantage of the adopted model is that it does not consider the lag caused by strain. In addition, when grinding, the process temperature and the deformation rate are significantly higher than when the machine parts rub together. It is shown that the condition of equal wear of the wheel surface is provided by equal wear of the abrasive grains on the entire working surface, the density of the working grains on the elementary section of the contact surface. The paper presents conditions under which equal-wear shapes of wheels working with a longitudinal feed are provided.

Grinding wheels remain very competitive in metalworking. Their large consumption in production is largely due to the loss of underutilized working grains removed by dressing, which restores the cutting ability and shape of the wheel surface. It is found that the grains located on the working surface are unevenly loaded. Moreover, the most susceptible to rapid loss from the binding material and wear are the grains located on the protrusions and edges of the wheel. The volume of the radial edge wear of the grains is 5-7 times greater than the average wear in the middle part of the working surface, so the shape of the wheel will tend to quasi-stabilization [5].

To increase the grinding process productivity with longitudinal feed for removing significant allowances, it is advisable to participate in the work of the entire working surface of the wheel. For example, with deep, centerless, flat rough grinding with the periphery or end face of the wheel [7,8].

The paper proposes a model of an equal-wear shape of the working surface of grinding wheels operating in the self-sharpening mode, where the principles of self-organization of tribosystems are used [6].

Initial information for determining the shapes of contacting surfaces is associated with the determination of physical and mechanical properties of the materials of the tool and the workpiece [3]: hardness, moduli of inelastic buckling, Poisson’s ratios, ultimate strength and yield strength, stiffness, viscosity and internal friction coefficients. These problems were solved using the theories of elasticity, plasticity, variational principles and thermodynamics of irreversible processes [4, 7], as well as analytical geometry and the theory of fracture [8, 9]. It is important to consider the properties and behavior of materials at high pressures and temperatures [9-10].
It was found that to obtain engineering solutions, the wheel should be considered as a ‘Voicht body’ [11] (in the terminology of [7] – ‘core’), crashing into the ‘Voicht medium’ [7]. A disadvantage of the adopted model is that the deformation delay from the strain is not considered, which is characteristic of the ‘Maxwell body’. It is compensated by the introduction of a private coefficient.

In modern research in the field of macro wear, energy approaches are used [6-11].

In them, the achievement of a quasi-stable shape is considered as a result of quasi-static deformation with a loss of mass. In this case, the processes in the zone of thermodynamic equilibrium are described by linear dependences. One of the important for optimizing the grinding process is the work by V.V. Schulz [5], where he, using the Voigt model, optimizes the shapes of parts and tools during friction. He obtained an integral that enables to calculate the optimum shape of the ‘core’ profile that provides minimum force P during its translational motion with constant velocity V in the Voicht medium.

The solution has the following form [7]

\[ y = \frac{f_{bh} E}{4 V \eta} x^2, \]  

(1)

where \( x \) and \( y \) – coordinates of points in the direction of the core depth and along the action of force \( P \), respectively; 
\( f_{bh} \) and \( \eta \) – coefficients of internal friction and viscosity of the Voigt medium. 
\( E, x^2, V \) - where.

An analysis of equation (1) yields important information about the shape of the wheel — at the point where the nucleus leaves the Voicht medium, the angle of inclination of its profile to the x axis is \( 35.2644^\circ \). This conclusion is valid for conditions when the energy consumption associated with rotation is significantly higher than with the translational movement of bodies [5]. To use the presented model, clarifications are needed.

When grinding, the process temperature and the deformation rate are significantly higher than when machine parts rub together. In addition, the model does not consider the time delay of the deformation from the strain \( \tau_{mod} \).

Taking into account the recommendations [13], as well as the relationship of the modified viscosity \( \eta_{mod} \) with the coefficient of internal friction \( Q^{-1} \) [4], formula (1) can be written in the following form

\[ y = \frac{P_z E_{mod}}{4 x P_y S_{np} \tau_{mod} K_{uls}} x^2, \]  

(2)

where \( P_z \) and \( P_y \) – tangential and normal technological cutting forces; 
\( S_{np} \) – longitudinal feed in the direction of technological force \( P_x \); 
\( E_{mod} \) – modified stiffness factor; 
\( K_{uls} \) – coefficient that takes into account the discrepancy between the friction process and the real grinding conditions.

Optimum performance of the grinding process depends on the wheel surface area. Based on formula (2), the total length of the intake part of the wheel is

\[ L \approx 2 \sqrt{\frac{P_z S_{np} \tau_{mod} K_{uls}}{P_y}}, \]  

(3)

where \( t_{A} \) - actual cutting depth.

The contact area of the wheel with the workpiece depends on their geometry and plunge conditions. Since the grinding wheel is more wear-resistant than the workpiece, a ‘convex’ branch is selected when calculating according to formulas (2) and (3).

Determination of stiffness and viscosity for the Voicht medium was found by micro-indentation, taking into account the recommendations [2].

Indentation was carried out by the DSI method on a DUH-202 device from SHIMADZU (Japan). A Berkovich diamond tip was used as an indenter.
Friction coefficients $f_{\text{friction}}$ were determined experimentally. With a steady shape of the wheel, the cutting forces were recorded, then the graphical integration of all specific normal $p_y$ and tangential forces $p_z$ was carried out according to the formula of the curve of the running-in circle. The ratio of the tangential and normal forces was taken as the coefficient of friction. Its value differed from the value obtained by the method of free vibrations through the logarithmic decrement of damping of the vibration amplitude and was refined according to the method [1,2].

The value of $E_{\text{mod}}$ was determined using the modifications of K. Magregor and I. Fisher [7,9], and viscosity - through the coefficient of internal friction $Q^{-1}$ [4,9]

$$\eta = a_B \times Q^{-1},$$

where $a_B$ – proportionality coefficient, Pa × s.

The values of $E_{\text{mod}}$ and $\mu_{\text{mod}}$ for various grinding conditions are given in [9].

The working wheel differs from the theoretical one in the following way (see Figure 1): the edges of the wheel quickly chip off and practically do not participate in the work; there is no gauging part on the wheel, however, it has an auxiliary working part, due to which a residual GFA macroscale is formed on the machined surface.

Figure 1. The diagram of work of an equal-wear grinding wheel.

A section of the AC profile is described by equation (2) - this is the intake, the main working part of the wheel with the height of $B_0$. Section AF – an auxiliary part with the height of $B_a$. Areas above and to the right of point C and above and to the left of point F are areas of edge wear.

The shape is reproduced while maintaining constant process conditions [9]. In case of artificial disturbance of the shape due to indentations [8], disturbance of the column of workpieces during centerless grinding [10-14], it is gradually restored.

The condition of equal wear of the wheel surface is ensured by equal wear of abrasive grains on the entire working surface. The load on the working grains depends on their density on the elementary section of the contact surface, location of the allowance to be removed, and the cut length. Both depend on the shape of the wheel and the workpiece, as well as conditions of their interaction.

We will roughly analyze the wear of the wheel due to geometric conditions of contact during centerless grinding. Let us assume that in one turn of the workpiece (see Figure 1) the generatrix of the wheel has shifted relative to the workpiece by the value $S$ ($S = 2B_a$) from the position GD to AC.
The material is removed with CDFAC section. Let us divide this section by horizontal lines into elementary sections with the height of $\Delta y$. The areas of these sections are approximately equal, and the volumes of the ground material by layers are different - the deeper the layer, the longer the contact and the greater the number of abrasive grains involved in cutting off the elementary volume.

An additional increase in the number of grains is not proportional to the contact area. It is associated with the angle of inclination of the elementary contact surface to the infeed direction - $\alpha_r$. If you do not take into account the influence of other factors - edge wear, loading conditions of grains along the profile, etc., then the proportion of the influence of the angle $\alpha_r$ is significant. For example, when $\alpha_r = 10^\circ (\sin 30^\circ = 0.5)$, the density of working grains increases by $\approx 1.41$ times, naturally, the load on a single grain should decrease significantly.

The paper presents conditions under which equal wear shapes of wheels working with longitudinal feed are provided. Using the results obtained and the analysis of works [7-10], the following practical conclusions can be drawn.

1. Equal wear wheel during grinding has 4 characteristic working surfaces: two edge zones of hard-to-control wear, intake and auxiliary.
2. The wheel works with the entire periphery, longitudinal feed occurs in one direction. Its value is equal to twice the height of the auxiliary working part.
3. The appearance on the wheel in front of the intake part of the cylindrical belt indicates underutilization of the performance of the intake part. It is necessary to increase the depth of the allowance to be removed or/and the longitudinal feed.
4. With longitudinal feed $S>2B_a$ the wheel profile is transformed into a triangular one. To reduce wheel wear, it is necessary to decrease the value of $S$.
5. The principle of equal wear of the wheel is realized only with increased rigidity of the technological system.

References
[1] Bulychev S.I. Test of materials by continuous indentation of the indenter / S. I. Bulychev, V.P. Alyokhin. - Moscow: Mashinostroenie, 1990. – 224 p.
[2] S.A. Fedosov, L. Pešek. Determining mechanical properties of materials by microindentation: Modern foreign methods. – Moscow.: Faculty of Physics of MSU, 2004. – 100 p.
[3] V. Nosov, B.A. Kravchenko. Technological bases of designing abrasive tools: Moscow: Mashinostroenie-1, 2003. 247 p.
[4] K.L. Johnson. Contact mechanics. CAMRIDGE UNIVERSITY PRESS. NEW YORK. NEW ROCHELLE. First paperback edition (with correction). – 1987. – 510 p.
[5] Shultz V.V. Form of natural wear of machine parts and tools / V. V. Shultz. - L.: Mashinostroenie, Leningrad dept., 1990. – 208 p.
[6] Goryacheva I. G. Contact problems in tribology/ I.G. Goryacheva, M.N. Dobychin. - M: Mashinostroenie, 1988. – 256 p.
[7] Evseev D.G. Physical bases of the grinding process / D.G. Evseev, A.N. Salnikov. Saratov: Saratov Publishing House, 1978 –128 p.
[8] Zakharenko I.P. Deep grinding circles of superhard materials/ I.P. Zakharenko, Yu.V. Savchenko, V.I. Lavrinenko. - Moscow: Mashinostroenie, 1988. – 56 p.
[9] Salov P.M. Principles of self-organization of wear of grinding wheels / P.M. Salov, B.A. Kravchenko-Samara: Samara State Technical University. UN-t, 2001. – 118 p.
[10] O.V. Zakharov, I.N. Bobrovskij, and A.V. Kochetkov. Analysis of methods for estimation of machine workpiece roundness. Procedia Engineering. 2016. Vol.150. pp. 963-968.
[11] O.V. Zakharov, A.F. Balaev and A.P. Bochkarev. Shaping of spherical surfaces on centerless superfinishing machines with longitudinal supply, Russian Engineering Research, 2015, Vol. 35, Issue 4. pp. 264-266.
[12] A.V. Korolev, A.A. Korolev, A.F. Balayev, B.M. Iznairov, O.V. Zakharov and A.N. Vasin. Probability nature of solid bodies destruction. International Journal of Applied Engineering Research. 2015. Vol. 10. Number 21. pp. 42692-42695.

[13] O.A. Yalovoy, O.V. Zakharov and A.V. Kochetkov. The centerless measurement of roundness with optimal adjustment. IOP Conf. Series: Materials of Science and Engineering. 2015. Vol. 93. 012024 p.

[14] O.A. Yalovoy, O.V. Zakharov and A.V. Kochetkov. Adaptive control of accuracy at centerless grinding of rolling bearings. IOP Conf. Series: Materials of Science and Engineering. 2015. Vol. 93. 012063 p.