ANALYTICAL PRESENTATION OF CUTTING TEMPERATURE TO DEVELOPMENT OF THE THEORETICAL THERMOMECHANICS OF GRINDING

Oleg Klenov, *Director PhD Eng., dimerus@dimerus.com,*
DiMerus Engineering Ltd., Kharkov, Ukraine
Feodor Novikov, *Prof. PhD Eng., fokusnic1@rambler.ru,*
Simon Kuznets Kharkov Nat. Univ. of Economics, Kharkov, Ukraine
Yury Gutsalenko, *Sen. Staff Scientist, gutsalenko@kpi.kharkov.ua,*
Nat. Tech. Univ. "Kharkov Polytech. Inst.", Kharkov, Ukraine

Abstract: The paper provides an analytical dependence for determining the cutting temperature during grinding taking into account physical material science and processing kinematic-geometric conditions of treatment. According to this dependence, with increasing the depth of grinding and corresponding processing productivity the cutting temperature initially increases, and then it asymptotically approaches to constant value that mainly determined by the energy intensity of the treatment. This theoretical solution is consistent with practical data and opens up new technological opportunities for controlling the thermal tension of the grinding process, as it opens the prospect of further increasing the processing productivity without actually increasing the cutting temperature. It is possible to realize this solution under condition of essential reduction of conditional cutting stresses (power consumption of processing). In contrast to the known approaches as a rule based on the experimental establishment of heat shares leaving into the workpiece and formed chips, the developed theoretical approach will allow us to more objectively assess the technological possibilities of reducing the cutting temperature during grinding and develop recommendations for their practical implementation. The basis of the design scheme is the well-known representation of the removable allowance by a set of adiabatic rods which are cut off during processing.

Keywords: grinding process, theoretical thermomechanics, thermal tension, cutting temperature, processing productivity, processing quality, conditional cutting stress, power consumption of processing.

Introduction

As is known, the grinding process is characterized by high heat stress, which leads to a decrease in the quality of processing by the appearance on the treated surfaces of burns, microcracks and other temperature defects. To reduce the heat stress of the process there are used grinding wheels characterized by high cutting ability, effective technological environments in order to reduce friction intensity in the cutting zone, etc. [1-4].

At the same time, it is not always possible to achieve the necessary reduction in the heat stress of the grinding process and, correspondingly, the cutting temperature. Therefore, it is important to know the laws of the grinding process associated with the reduction of the cutting temperature, which requires the development of a mathematical model for the formation of the cutting temperature during grinding, taking into account the heat distribution that leaves into the workpiece and the formed chips [5].

Such a theoretical approach, unlike the known approaches which based, as a rule, on the experimental establishment of heat shares leaving into the workpiece and chips, will allow more objective evaluation of the technological possibilities of reducing the cutting temperature during grinding and to develop of recommendations for their practical implementation.

Analytical research

The removable allowance from the workpiece is represented as an infinite set of adiabatic rods of length $l_1 + l_2$ and cross-sectional area S located normal to the surface which being treated [1, 5, 6]. The calculation scheme is shown in Fig. 1. When deep grinding, it is necessary to take into account the cutting by the grinding wheel of a part of the adiabatic rod $l_1 = t$ with the speed

$$V = V_{det} \cdot \sqrt{\frac{t}{D_c}}, \quad (1)$$

where V_{det} is the speed of the part, m/s; t – depth of grinding, m; D_c – diameter of the circle, m; l_2 is the depth of penetration of heat into the surface layer of the workpiece, m [7–9].

This is equivalent to moving of the heat source along the normal to the treated surface (i.e. along the adiabatic rod) at a speed V.

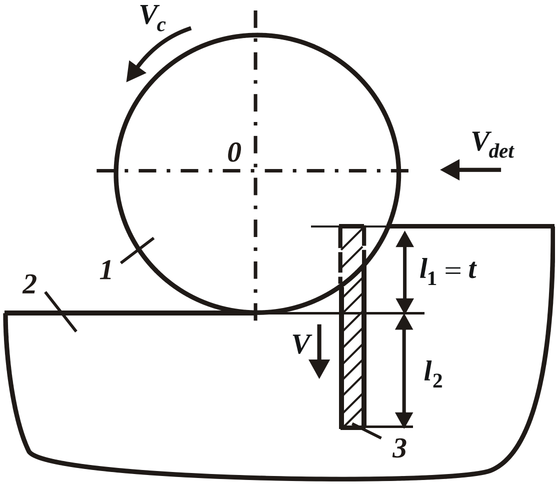

Fig. 1 – Calculation scheme of cutting temperature for flat deep grinding:
1 – grinding wheel; 2 – treated workpiece;
3 – adiabatic rod

The amount of heat Q_1 expended on heating of the adiabatic rod with length $l_1 + l_2$ is equal to

$$Q_1 = c \cdot \rho \cdot S \cdot t \cdot \theta + 0{,}5 \cdot c \cdot \rho \cdot S \cdot l_2 \cdot \theta, \quad (2)$$

where c – specific heat of the processed material, J/(kg·K); ρ – density of the processed material, kg/m^3.

The coefficient 0.5 takes into account the uneven heating of the lower part of the adiabatic rod along the length l_2.

The amount of heat Q_2 expended on heating a part of the adiabatic rod on length l_2 according to the thermal conductivity of the processed material is expressed by:

$$Q_2 = \lambda \cdot S \cdot \frac{\theta}{l_2} \cdot \tau_2, \quad (3)$$

where λ – coefficient of thermal conductivity of the processed material, W/m·K; τ_2 – the time of action of the heat source when the part of the adiabatic rod is heated on a length l_2, s.

The amount of heat Q_2 is also expressed by the dependence $Q_2 = q \cdot S \cdot \tau_2$. Then we have solving the dependence (3) with respect to length l_2:

$$l_2 = \frac{\lambda \cdot \theta}{q}, \quad (4)$$

where $q = \frac{P_z \cdot V_c}{F} = \frac{\sigma \cdot Q}{B \cdot \sqrt{t \cdot D_c}}$ – density of heat flow, W/m^2; $P_z = \sigma \cdot \frac{Q}{V_c}$ – tangential component of the cutting force, N; σ – conditional cutting stress (energy intensity of treatment), N/m^2; $Q = B \cdot V_{det} \cdot t$ – processing productivity, m^3/s; V_c – speed of the grinding wheel, m/s; $F = B \cdot \sqrt{t \cdot D_c}$ – contact area of the grinding wheel with the processed material, m^2; B – width of grinding, m; D_c – diameter of the wheel, m.

We obtained a quadratic equation for the cutting temperature during grinding θ taking $Q_1 = q \cdot S \cdot \tau_1$ and substituting the dependence (4) in (2):

$$\theta^2 + \frac{2 \cdot q \cdot t}{\lambda} \cdot \theta - \frac{2 \cdot q^2 \cdot \tau_1}{\lambda \cdot c \cdot \rho} = 0, \quad (5)$$

where $\tau_1 = t/V$ – the contact time of the grinding wheel with the adiabatic rod, equal to the time of its cutting by the grinding wheel, s.

The solution of the quadratic equation (5) is:

$$\theta = \frac{2 \cdot q}{c \cdot \rho \cdot V_{det}} \cdot \sqrt{\frac{D_c}{t}} \cdot \frac{1}{\left[\sqrt{1 + \frac{2 \cdot \lambda \cdot \sqrt{D_c}}{c \cdot \rho \cdot V_{det} \cdot t^{1,5}}} + 1\right]} . \quad (6)$$

The cutting temperature during grinding θ described by the dependence (6) takes the following form with account $q = \frac{\sigma \cdot Q}{B \cdot \sqrt{t \cdot D_c}}$:

$$\theta = \frac{\sigma}{c \cdot \rho} \cdot \frac{2}{\left[\sqrt{1 + \frac{2 \cdot \lambda \cdot \sqrt{D_c}}{c \cdot \rho \cdot V_{det} \cdot t^{1,5}}} + 1\right]} . \quad (7)$$

As can be seen (Fig. 2), the cutting temperature during grinding θ increases continuously with increasing of the component speed V_{det} and grinding depth *t*, and asymptotically approaches to the maximum value $\sigma/(c \cdot \rho)$ determined by the heating temperature of a part of the adiabatic rod of length t.

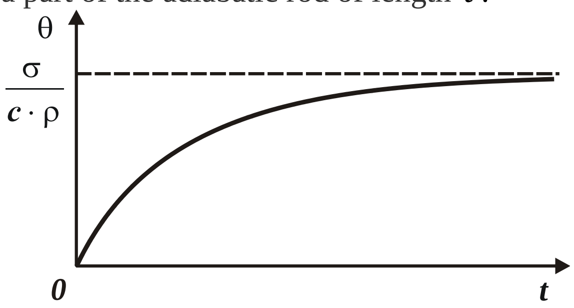

Fig. 2 – General view of the dependence of the cutting temperature θ from the depth of grinding t

In this case, all the heat generated during the grinding process goes to the formed chips. In terms of providing high-quality processing this is an ideal case of grinding because the heat generated during processing and usually leads to the formation of temperature defects on the treated surface will not actually leave into the surface layer of the workpiece. However, it is difficult to fulfill this condition during grinding due to relatively small ranges of the parameters of the cutting regime V_{det} and t. This condition is feasible when high-speed cutting by blade tools.

In fact, this determines the effectiveness of the practical use of high-speed processing, which is widely used in finishing operations to ensure high quality processing, for example, instead of the grinding operation for avoiding the formation of temperature defects on the treated surfaces.

The dependence (7) can be transformed with account of processing productivity $Q = B \cdot V_{det} \cdot t = \text{const}$:

$$\theta = \frac{\sigma}{c \cdot \rho} \cdot \frac{2}{\left[\sqrt{1 + \frac{2 \cdot B \cdot \lambda \cdot \sqrt{D_c}}{c \cdot \rho \cdot Q \cdot t^{0,5}}} + 1\right]} . \quad (8)$$

It is obviously from (8) that reducing the depth of grinding t effectively increase the temperature at grinding cutting θ for a given processing productivity Q. However, the depth of grinding t slightly affects on θ. Therefore, grinding can be carried out using multipass and depth schemes in fact with the same efficiency.

As also follows from (8), the conditional cutting stress has the greatest influence on the cutting temperature during grinding: the smaller σ, the proportionally smaller θ.

Conclusion

The obtained dependence of the cutting temperature during grinding is applicable to certain fixed states of the technological processing system characterized by a constant depth and processing productivity. Such a state is most fully inherent in the implementation of grinding methods with the possibility of rational stabilization of the cutting ability of diamond-abrasive tools, especially with their electrical cathodic electrochemical or anode electro-erosion dressing in the cutting zone [10].

В связи с аналитически установленной центральной ролью условного напряжения резания σ в формировании термомеханической нагрузки процесса шлифования важно провести углубленный теоретический анализ закономерностей изменения σ с целью выявления путей производительной рационализации одно- и многопереходных операций алмазно-абразивной обработки, а также многооперационных циклов шлифования в направлении организации энергетически более выгодных производств.

It is important to perform an in-depth theoretical analysis of the patterns of change σ in connection with the analytically established central role of the conditional cutting stress in the formation of the thermomechanical load of the grinding process and in order to identify of ways for efficient rationalization of single- and multi-transition diamond-abrasive operations, as well as multi-operation grinding cycles. Developments in this direction contribute to the organization of energetically more profitable productions.

Bibliography

[1] **Yakimov, A. V.** *Optimization of the grinding process*. Moscow, Mashinostroenie, 1975, 175 p. – In Russian.

[2] *Abrasive and diamond processing of materials*. Ed. by **A. N. Reznikov.** Moscow, Mashinostroenie, 1977, 390 p. – In Russian.

[3] **Evseev, D. G.** *Formation of the properties of surface layers in abrasive processing*. Saratov, Publishing House of the Saratov University, 1975, 127 p. – In Russian.

[4] **Silin, S. S.** The similarity method for cutting materials. Moscow, Mashinostroenie, 1979, 152 p. – In Russian.

[5] **Yakimov, A. V.**, et al. *Theoretical bases of material's cutting and grinding*. Odessa, Odessa Nat. Polytech. Univ., 1999, 450 p. – In Russian.

[6] **Novikov, F. V.,** and **S. M. Yatsenko.** Increase in the efficiency of the technology for finishing the details of friction pairs of piston pumps. *Physical and Computer Technologies. Proceedings of the 13th International Scientific and Practical Conference, April 19-20, 2007, Kharkov.* SE KhMP "FED", 2017, 8-20. – In Russian.

[7] **Novikov, F. V.,** and **O. S. Klenov.** Theoretical substantiation of conditions for increasing the efficiency of high-speed processing. *Bulletin of NTU "KhPI"*. 2014, No. 42(1085), 106-111. – In Russian.

[8] **Klenov, O. S.** Mathematical modeling of the parameters of the thermal process under abrasive and blade treatments. *Reliability of the instrument and optimization of technological systems*. 2014, No. 35, 19-25. – In Russian.

[9] **Klenov, O. S.** Determination of the parameters of the thermal process during grinding and blade processing. *Perspective technologies and devices*. Lutsk, Lutsk NTU, 2017, No.10 (1), 69-75. – In Russian.

[10] **Bezzubenko N. K.,** and **Yu. G. Gutsalenko**. Intensive grinding and special design machines. *Eastern-European Journal of Enterprise Technologies*. 2010, No. 5/1(47), pp. 70-71. – In Russian.

[11] **Gutsalenko, Yu. G.** *Diamond-spark grinding of high functionality materials* [Online resource]. Kharkov, Cursor, NPU «KhPI», 2016, 272 p. [3,75 Мб], access code: http://web.kpi.kharkov.ua/cutting/dsghfm-monograph.pdf. – In Russian.