ANALYTICAL DETERMINATION OF CONDITIONS FOR PRODUCTIVITY IMPROVEMENT OF DIAMOND GRINDING

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Abstract: *The analytical dependences for definition of processing productivity when grinding by diamond wheels on metal bonds with the accounting of linear wear of the grain which is the most acting over the level of bond are given on the basis of probability-theoretic approach.. Conditions of electroerosive dressing with providing the optimum cutting relief of diamond wheel are defined. A high-performance process of longitudinal external cylindrical diamond grinding of fast-cutting and hard-alloy multiedge tools (mills, reamers, core drills, etc.) is developed with high quality of processing and renting allowance to 1,2 mm per side in one pass.*

Keywords: diamond grinding, a diamond wheel on a metal bond, processing productivity, quality of processing, the optimum cutting relief.

1. INTRODUCTION

Diamond grinding became an important factor of scientific and technical progress in mechanical engineering when machining the details made of materials with the increased physic-mechanical properties. First of all it belongs to processing of metal and nonmetallic materials of the increased hardness (hard alloys, wearproof surfacing and coverings, diamonds, ceramics and ferrite, technical glass, crystal, etc.). For their processing Diamond wheels on tear-proof metal bonds working in the mode of continuous or periodic electroerosive (electrochemical) dressing are used for their processing with providing the high rates of quality and productivity of processing [1-3]. At the same time it is necessary to approach to the choice of optimum conditions of processing with scientifically reasonably effective use potential opportunities of these wheels. Therefore the task of research consist of analytically determination of the conditions for high productivities of diamond grinding and also to develop the method of deep diamond grinding of hard-alloy and fast-cutting multiedge tools.

2. ANALYTICAL RESEARCH

In general the depth of insertion of the cutting grain into the processed material for microcutting (H) is determined by the hardness (by Vickers) of the processed material (HV) and radial force P_{y1} which acting on the cutting grain. Then, for a conical model of grain with an angle 2γ at its top [1]:

$$H = \sqrt{\frac{P_{y1}}{\pi \cdot tg^2\gamma \cdot HV}} . \qquad (1)$$

As follows from the dependence (1), the greater the hardness of the processed material *HV* and less strength P_{y1}, the lower the depth of grain introduction *H*. Consequently, when grinding hard-to-work materials, the depth *H* will be small. Coefficient $(1-\varepsilon)=H/\overline{X}$, which determines the degree of protrusion of the grain over the level of a bond of a diamond weel and changes within the limits 0 ... 1, under the condition $b=H$ also will be small (b is the maximum height of the protrusion of the vertices of the grains over the level of the bond of the wheel, m; $\overline{X}$ is the grain size of the wheel, m). However, it does not follow from this that the decrease in the productivity of processing Q determined by the dependence which obtained on the basis of the theoretical-probabilistic approach for grinding [1]:

$$Q=\frac{S\cdot tg\gamma\cdot m\cdot V'_{\text{det}}\cdot(1-\varepsilon)^3\cdot(1-\eta^2)}{600\cdot\pi}, \quad (2)$$

where S is the cross-sectional area of the straight-line workpiece (plate) with moving at a constant speed V'_{det} in normal to the working surface of the diamond wheel, m^2 (Fig. 1); $\eta=x/H$ is the dimensionless coefficient taking into account the degree of blunting of the grains, varies within the range 0 ... 1 ($\eta\rightarrow 0$ for sharp grain, $\eta\rightarrow 1$ for blunted grain); x - linear wear value for the diamond grain with maximum protruding above the level of the bond of the wheel, m; H - conditional maximum depth of introduction of the processed material into the working surface of the wheel measured from the nominally (without wear) maximum protruding grain, m.

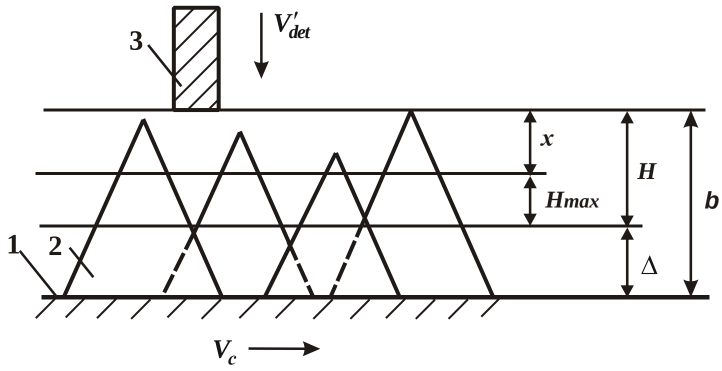

Fig. 1. *Calculation scheme of the parameters of the grinding process: 1 - level of the bond; 2 - cutting grain; 3 - processed sample.*

This is due to the fact that, simultaneously with the decrease in the maximum height protrusion of grain above the level of a wheel bond $b=H$, less coefficient

$$\eta=\sqrt{1-\frac{9\cdot V'_{\text{det}}}{tg\gamma\cdot k\cdot V_c\cdot b^2}}; \quad (3)$$

this makes it possible to compensate of decrease in processing capacity Q with considering the reduction of the dimensionless coefficient $(1-\varepsilon)$. In (3): V'_{det} - speed of movement the processed sample along the normal to the working surface of the wheel, m/s; k - surface concentration of grain of a wheel, pcs/m^2.

It is established that the main condition for increasing productivity processing Q when grinding high hardness materials is to maintain the diamond wheel of "sharp" cutting relief ($\eta \to 0$). This is achieved by work the diamond wheel in self-sharpening mode by applying relatively resistant organic or ceramic bonds, or the work of a diamond wheel on metal bonds in the regime of its continuous erosion dressing.

It is known when the grain size of the diamond wheel increases then the strength of the grain on crushing (determined by a destructive load equal to P_1) increases too by dependence $P_1 = \alpha \cdot A^{\beta}$, where α and $\beta < 1$ are constants [2]. Then the coefficient $(1-\varepsilon) = H / \overline{X}$ is determined with account the dependence (1):

$$(1-\varepsilon) = \frac{1}{\overline{X}^{(1-0,5\beta)}} \cdot \sqrt{\frac{\alpha}{\pi \cdot tg^2\gamma \cdot HV}}. \tag{4}$$

As can be seen from (4) the coefficient $(1-\varepsilon)$ the larger the smaller the graininess of the wheel $\overline{X}$ and more parameter α, which determines the relative strength of grains of various marks of diamonds. Therefore, according to the dependence (2), it is necessary application of fine-grained diamond wheels with increased strength of diamond grains to increase the processing efficiency Q when processing materials of high hardness. The granularity of the diamond wheel should be chosen inversely proportional to the hardness of the processed material taking into account that the parameters $\overline{X}$ and HV (4) with approximately the same degree (equal to 0.5).

According to the dependence (4), reducing the graininess of a wheel $\overline{X}$ leads to increase in the $(1-\varepsilon)$, i. e. increase the degree of protrusion of grain over the level of the bond of the wheel and the reduction of the part of the grain located in the bond of the wheel.

Therefore, the strength of grain retention will decrease and it is necessary use more strong metal bonds of a diamond wheel to increase it.

The efficient life of diamond wheels is determined by the range of variation of the ratio $\eta = 0 \ ... \ \eta_1 < 1$. The higher the value η_1, the higher the stability of the wheel. Increase value η_1 requires an increase in the parameter H, according to

$$H = \sqrt[3]{\frac{9b \cdot V'_{det}}{tg\gamma \cdot k \cdot V_c \cdot (1-\eta^2)}}, \tag{5}$$

and coefficient $(1-\varepsilon)$, according to the dependence (4). Therefore, to increase the diamond wheel durability can be due to an increase in the height of the protrusion of grains above the bond level, the use of stronger metal bonds and methods of opening of diamond layer of the wheel, for example, EDM.

In the general case, for a more correct presentation of technological possibilities of diamond grinding in the design scheme shown in fig. 1, the parameter *b* should be considered as the sum of two terms: $b = H + \varDelta$, where $\varDelta$ is the height of the intergranular space of the wheel, occupied by chips and other processing products, determined by the dependence: $\varDelta = \xi \cdot \varDelta_0$, where: ξ is the coefficient, taking into account the degree of filling of the intergrain space of the wheel with the chips ($\xi > 1$); $\varDelta_0$ is the thickness of the conditional layer of the "melted" processed material, which is formed by one rotation of the wheel, m.

The following relationships are valid for cylindrical longitudinal grinding [1]:

$$\varDelta_0 = \frac{S_t}{B} = \frac{Q}{V_c \cdot B} = \frac{B \cdot V_{det} \cdot t}{V_c \cdot B} = \frac{V_{det} \cdot t}{V_c}, \tag{6}$$

where $S_t = Q / V_c$ - instantaneous total cutting section from all simultaneously working wheel grains, m^2; *B* – is the width of the circle, m.

Obviously, the smaller the parameter $\varDelta$, the greater the processing capacity *Q* when grinding. Consequently, ideally, it is necessary to strive to fulfill two conditions: $\xi \to 1$; $b \approx H$.

According to the theoretical studies carried out for ordinary diamond grinding of carbide details, coefficient ξ varies from 100 to 1000 and more. Therefore, its decrease, for example, in 10 times, will allow the same number of times to improve a processing performance. When diamond grinding of various steel, titanium alloys and other relatively plastic materials, the coefficient ξ is yet more, and the effect of processing from decreasing ξ for such materials there may be more higher. It can be achieved a significant reduction in the coefficient ξ by application of various methods of vibratory and ultrasonic chip shredding improving its placement on the working surface of the diamond wheel.

The diamond electro-erosion grinding [1] (or diamond-spark grinding in the terminology of the organization-developer [3]) has significantly more technological opportunities among others combined grinding methods, providing dissolution, reflow or the combustion of chips in the cutting zone. It can be approximated the coefficient ξ value to the value ξ=1 at optimum conditions of diamond electro-erosive grinding and turn the cutting relief of diamond wheel into a fully active one, in which the complete removal (cut) of the metal in a cutting zone is being processed at the level of the bond of the wheel.

Thus a developed cutting relief and high resistance of the diamond wheel at the maximum realization of it potential provides with the correct assignment of mechanical and electrical modes of diamond electro-erosion grinding due to the effective use of the energy of electrical discharges in the impact on a bond of diamond wheel and chips.

In view of the above it is important to carry out an analysis of the external cylindrical diamond grinding (Fig. 1) for the conditions $\xi \to 1$ and $b \approx H$ which can be realized due to the methodology and practice of diamond electro-erosion grinding [4]. In this case dependences for parameters *H*, η and *Q* have the forms [5]:

$$H = \sqrt[3]{\frac{9b \cdot V_{det} \cdot \sqrt{2t \cdot \rho}}{tg\gamma \cdot k \cdot V_c \cdot (1-\eta^2)}}; \tag{7}$$

$$\eta = \sqrt{1 - \frac{9 \cdot V_{det} \cdot \sqrt{2t \cdot \rho}}{tg\gamma \cdot k \cdot V_c \cdot b^2}}; \tag{8}$$

$$Q = S_0 \cdot V_{det} \cdot t = \frac{S_0 \cdot tg^2\gamma \cdot k^2 \cdot b^4 \cdot V_c^2 \cdot (1-\eta^2)^2}{162 \cdot V_{det} \cdot \rho}, \tag{9}$$

where V_{det} - speed of the workpiece, m/s; $V'_{det} = V_{det} \cdot \sqrt{2t \cdot \rho}$; t - depth of grinding, m; S_0 - longitudinal feed, m/s; $\rho = \frac{1}{R_c} + \frac{1}{R_{det}}$; R_c, R_{det} - the radius of the wheel and the detail, m.

According with the dependence (9) an increase in hardness of the processed material *HV* leads to a decrease in the parameter $b = H$ and coefficient $(1-\varepsilon)$, and consequently in the processing capacity *Q*. In accordance with the dependence (8) it is possible to achieve the increasing of processing capacity *Q* by decrease a coefficient η at realizing regime self-sharpening of a diamond wheel on an organic or ceramic bond or regime of autonomous dressing of the diamond wheel on metal bond. Obviously, the approach with the choice of the optimal bond for providing the work of diamond wheel in self-sharpening mode when $b = H$ is more universal.

An important condition for improving grinding performance of hard-to-work materials should also be considered a reduction in speed the details V_{det} and increasing the longitudinal feed S_0, depending on

$$\eta = \sqrt{1 - \frac{9 \cdot \sqrt{2 \cdot V_{det} \cdot Q \cdot \rho}}{tg\gamma \cdot k \cdot V_c \cdot b^2 \cdot \sqrt{S_0}}}, \tag{10}$$

in connection with the decrease in the parameter *b*, saving the parameters η and *Q* constant.

The depth *t* must then increase from the $Q = S_0 \cdot V_{det} \cdot t = const$. Hence, with increasing the hardness of the processed material to effectively use the scheme deep grinding with a relatively low speed of the workpiece $V_{\partial em}$ at longitudinal feed $S_0 \cong B$ (where *B* is the height of the wheel, m). On this basis it was developed a high-productivity process of longitudinal external cylindrical diamond grinding of fast-cutting and hard-alloy multiedge tools (mills, reamers, core drills, etc.) is developed with high quality of processing and renting allowance to 1,2 mm per side in one pass.

Grinding according to the proposed scheme is carried out with $B_1 = 0{,}9 \cdot B$ and V_{det}=1.5 m/min, which allows to increase the processing capacity *Q* in 1,5 ... 2 times at economically reasonable costs for the consumption of diamond material unlike existing processes of deep grinding where the longitudinal feed per revolution of the workpiece B_1 not exceeds 0.1 of the width of the wheel B and the rotation speed of the workpiece V_{det} is 20 ... 30 м/min.

The effectiveness of this method of grinding has become possible thanks to specially developed principles for assigning the parameters of the cutting mode according to which the search for optimal grinding conditions should be from the condition of ensuring the complete removal of metal at the level of allowable (strength) thickness of the cut when the specific consumption of diamond takes minimum for any relief of the wheel, size and concentration of it grains.

The performed analytical studies have shown that for determining the optimum grinding mode is sufficient to know the permissible (strength) cutting thickness $H_{\max}$, which is established by calculation and experimentation:

$$V_{det} = \frac{tg\gamma \cdot k \cdot V_{\kappa p} \cdot H_{max}^3}{9 \cdot b \cdot \sqrt{2 \cdot t \cdot \rho}}. \tag{11}$$

Analytical dependency for determining H_{max},

$$H_{max} = \sqrt[3]{\frac{9 \cdot b}{tg\gamma \cdot k \cdot V_c}} \cdot \sqrt[6]{\frac{2 \cdot \rho \cdot V_{det} \cdot Q}{B}}, \tag{12}$$

proposed for comparison of the considered above sheme and conventional practice of deep grinding proposed for comparison of the proposed scheme and conventional practice of deep grinding. Operating with dependency (12) confirms the efficiency of reducing the speed of the workpiece V_{det} from point of view increasing processing capacity Q, and, consequently, the advantage of the scheme with longitudinal feed B_1 approximately equal to the width of the wheel B at conditions of increased depths of grinding.

It is possible to increase the processing capacity Q from (9) by reduce the speed of the part V_{det} while saving the values η and Q in dependence (10) for solution of technological tasks of grinding applied to materials with a high hardness when a value of the maximum height of protrusion of the tops of grains above the level of diamond bonds b is small. Decrease V_{det} admits increase in grinding depth t from condition $Q = const$. The greatest effect is achieved under the condition $t = R_{det}$. This condition can be realized by abrasive forming of deep cutouts, grinding of deep grooves, abrasive sawing, as well as with flat grinding by face wheel with rotating machine table when parameters $t = R_{det}$ and S_0 which enter into the dependence (10) are considered respectively as the grinding width and the depth of grinding.

3. CONCLUSION

The analytical dependences for definition of processing productivity when grinding by diamond wheels on metal bonds with the accounting of linear wear of the grain which is the most acting over the level of bond received on the basis of probability-theoretic approach are marked and discussed.

Received theoretical results are tested in the developments and applications of stable processes of high-performance diamond grinding with electro-physical stimulation of processing and others [4, 6].

Analysis and practice of realizations of theoretical research results develop experience of work-out of diamond-spark grinding technique, tools and technologies in the Kharkov Scientific School of Physics of Cutting and indicate the prospects for further research in this direction.

REFERENCES

[1] Physico-mathematical theory of the processes of material's treatment and engineering technology. Ed. by **F. V. Novikov and A. V. Yakimov**. In 10 vols. Vol. 1: *Mechanics of material cutting*, Odessa, Odessa Nat. Polytech. Univ., 2002, 580 p. – In Russian.

[2] **Lavrinenko, V. I., and N. V. Novikov.** *Superhard abrasive materials in machining*. Kiev, ISM of NAS of Ukraine, 2013, 456 c. – In Ukrainian.

[3] **Gutsalenko, Yu. G.** Diamond-spark grinding: an overview of the Fortieth Anniversary of the development of the Kharkov Scientific School of Physics of Cutting. *Physical and Computer Technologies. Proceedings of the 18th International Scientific and Practical Conference, December 5-6, 2012, Kharkov.* SE KhMP "FED", 2012, pp. 79-88. – In Russian.

[4] **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.

[5] **Yakimov, A. V., F. V. Novikov, G. V. Novikov, B. S. Serov, and A. A. Yakimov.** *Theoretical bases of material's cutting and grinding*. Odessa, Odessa Nat. Polytech. Univ., 1999, 450 p. – In Russian.

[6] **Novikov, F. V., and I. A. Ryabenkov.** *Finish machining processing details*. Kharkov, Simon Kuznets Kharkov Nat. Univ. of Economics, 2016, 270 p. – In Ukrainian.