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Original Article

Influence of variable cutting surface contact area on the components of cutting forces and accuracy

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ABSTRACT

The article discusses the process of diamond honing of conical holes. The purpose of the article is to identify the dependence of power in the process of cutting and the effect of changing the contact areas of the components of the cutting forces. The experiments were carried out on a developed installation to determine the cutting ability of diamond honing stones. Dependences of linear removal of steel 50 and steel 45 on the applied pressure have been established. Based on the data obtained, it can be concluded that if the value of the Py index goes beyond the limits of pure contact, then this leads to the seizure of surfaces and a deterioration in the quality of processing.

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INTRODUCTION

Currently, the diamond honing process has great potential for removing large allowances and intensively correcting significant initial errors in the geometric shape of the surface being machined. Therefore, the processing of surfaces made of various materials by the method of diamond honing is becoming more and more widespread in the automotive, aviation, food industries, oil, gas and other mechanical engineering industries.

One of the effective areas of using the technological capabilities of the diamond honing process is its use in the processing of precise conical surfaces, which include pumps for acid-washing treatment of oil wells, downhole pumps, shut-off valves, gate valves and taps for regulating oil and gas flows. In all of the above and similar structures, there are conical surfaces that ensure tightness in the joints.

Theory

Consider the contact interaction of a diamond bar with a workpiece during conical honing. According to the theory, during abrasive destruction of the material with a speed of up to and pure sliding of the bar on the treated surface, there is a change in force indicators [1]. The consequence of this is a variable value of the contact area of the bar during its movement along the generatrix of the hole being machined. According to the theory, during abrasive destruction of the material at a speed of less than 1 mps and pure sliding of the bar on the treated surface, changes in the force parameters [1]. As follows, this is the variable value of the

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contact area of the bar in the process of moving along the generatrix of the hole to be machined.

The complexity of the analysis of force dependences in abrasive destruction is that until now there is no single indicator of the machinability of materials with an abrasive tool. In work [2], the authors show the relationship between the machinability of steel and the wear of an abrasive tool. It is investigated in experiments with individual grains of various abrasive materials, which makes it possible to derive a regression equation reflecting the qualitative characteristics of the process, such as the starting point, the presence of an extremum and asymptotic behavior. The author of [3] was presents a mathematic model to calculate the blunting area of an abrasive grain whereby the main mechanisms of its wear such as mechanical and physicochemical phenomena are taken into account. Suggested mathematic model is the first to consider nonlinear back-coupling, taking into account the size of the blunting area. Krishnan R.K. and Vettivel S.C. [4] in work, was influence of grinding parameters like work speed and depth of cut on grinding forces and energy was studied. In the work of the authors [5] an attempt has been made to develop an empirical model to predict the surface roughness of ground glass fiber reinforced polymer composite laminate with respect to the influencing grinding parameters by factorial design approach of design of experiments. Kozlov and al. [6] in investigated grain interaction with the machined surface with an account of the grain's spatial orientation. Mathematical dependencies that determine the arrangement of grain in the tool's working space are presented. With the account of the proposed approach, a method is presented for determining cutting and deforming abrasive grains on the tool working surface on the basis of computer modeling, as well as modeling results in comparison with data from other researchers. In [7] the results of studying the effect of the grain shape on abrasive disc performance are presented. It is found that the grain shape is an essential feature that predetermines abrasive tool performance to a greater extent. Authors in [8] the results of studies of the effect of the trajectory grid density on the roughness parameters during cylinder honing are presented. Mathematical functions for calculating the roughness parameters were obtained. This functions works when changing the grid density of the tool path during honing with an abrasive of different grain sizes. Voronov in his work [9] are modeled cutting forces as friction forces that depend on a normal pressure on a contact surface, and removal of allowance during passage of the surface by cutting bars is modeled according to Preston's hypothesis. In addition, there is no indicator of the cutting ability of the tool, which tends to decrease under the influence of wear of the cutting edges and is continuously restored under the influence of self-sharpening.

If, in grinding modes, the analysis of the force dependences is complicated by the heating of the contact zone, the presence of sludge and a continuous change in the cutting ability, then for honing, without taking into account the wear of the cutting surface, the problem is easier to solve. For this reason, the theory of abrasive destruction of materials, according to [1], provides for the cutting speed to 1 mps, since 0 from to 1 mps, the speed does not significantly affect the power parameters. With a good opening of the abrasive surface of diamond bars, the dependence of the destroyed volume of the material on the specific pressure P, pressing the sample to the surface of the bar is linear, and the pressure is determined by the equality:

$$P = \frac{P_y}{F_c}, \tag{1}$$

where F_c - is the area of contact with the treated surface; P_y – radial cutting force.

Empirically it has been proved that the workability of the material can be characterized by the value of the relative resistance

$$\varepsilon = \frac{\Delta h_{et}}{\Delta h_{mat}}, \tag{2}$$

where Δh_{et} is the linear wear of the reference material under regulated conditions, mm;

Δh - linear wear of the test material under the same regulated conditions, mm.

The specified conditions provide for constancy, which maintains a linear dependence of Δh on P and a constancy of the sliding path, ensuring the same cutting ability of the abrasive tool.

The value ε in formula (2) reflects the relative resistance of the material to abrasive destruction, which is determined by the professor M. Khrushchev [10]. This value is used as a standard indicator and meets the conditions under the following processing conditions:

- diameter of the processed sample - 2 mm;
- clamping force (normal component of the cutting force) – P_c=0.03MPa;
- the length of the sliding path of the sample over the surface of the bar is L=3000 mm.

The index of the cutting ability of an abrasive surface is defined as an area equal to 1 mm^2, and the unit of measurement is the value of the relative instantaneous section of the cut of the etalon material under regulated conditions, namely:

d=2 mm, P_y=0.03MPa, L=3000 mm, ε=1.

Then the values of the cutting ability of the abrasive material can be expressed as:

$$\psi = \frac{\Delta h_{et}}{L} = \frac{1,5}{3000} = 500 \cdot 10^{-6} \tag{3}$$

Specific work of abrasive destruction:

$$a_{abr} = \frac{P_z \cdot L}{V_{mat}}, \quad (4)$$

where V_{mat} - is the volume of destroyed material.
Experimental data processing showed that:

$$a_{abr} = \frac{\varepsilon}{\beta}, \quad (5)$$

where β=4.5+0.0035HV. Hence:

$$\frac{P_z}{P_y} = \frac{5{,}3}{4{,}5 + 0{,}0035HV} \cdot \frac{\psi'}{500 \cdot 10^{-6}}, \quad (6)$$

where $\psi' = 10{,}5 \cdot \psi \cdot P_y$

Consequently, the theory of abrasive fracture determines the amount of linear removal of any solid during its pure sliding on an abrasive surface at a speed not exceeding 1 mps the following basic equation:

$$\Delta h_{mat} = \frac{1{,}5}{\varepsilon} \cdot \frac{L}{3000} \cdot \frac{\pi \cdot P_y}{0{,}3} \cdot \frac{\psi'}{500 \cdot 10^{-6}} = \frac{10{,}5 \cdot \psi' \cdot P_y \cdot L}{\varepsilon} \quad (7)$$

The value ψ' is determined by the equality:

$$\psi' = \frac{\Delta h_{mat}}{L} \cdot \frac{\varepsilon}{10{,}5} \quad (8)$$

at pressure:

$$P_y = \frac{0{,}3}{\pi} \quad (9)$$

Using these formulas, the value η is determined, which in all cases is equal to the product of the indicator, which depends on the material property, equal to $\frac{5{,}3}{\beta}$ and the relative value of the properties of the cutting surface, equal to $\frac{\psi'}{500 \cdot 10^{-6}}$.

Thus:

$$\eta = \frac{P_y}{P_z} = \frac{10{,}5 \cdot \psi \cdot 10^4}{\beta} \quad (10)$$

When moving from the scheme shown in Figure 1 to the scheme for honing conical surfaces, where the machined and abrasive surfaces have changed places, Δh_{mat} is determined by the formula:

$$\Delta h_{mat} = \frac{7 \cdot \psi' \cdot l \cdot P_y}{\varepsilon}, \quad (11)$$

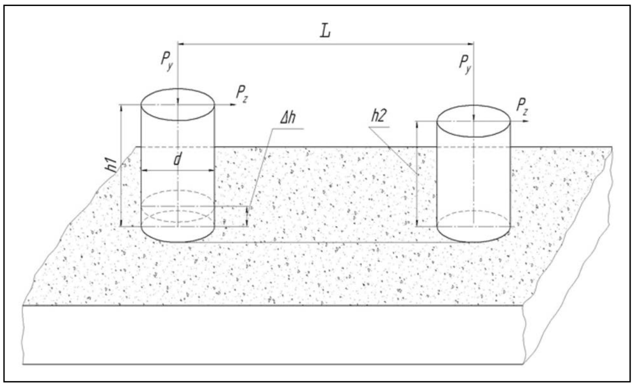

Figure 1. Scheme for determining the cutting ability of a diamond bar at processing of various materials: P_y – radial cutting force, MPa; P_z – tangential cutting force, MPa; d – diameter of the test material sample, mm; h_1 and h_2 – sample height, respectively, before and after processing, mm; Δh – the amount of linear material removal, mm; L – length of the path traversed by the sample on the abrasive surface, mm.

where l - the length of the bar's path in the direction of movement, mm.

As you know, the resulting speed is found from the equality. Knowing the ε and HV of the material under study, linear removal will depend only on the cutting ability of the bar.

Due to the lack of experimental data on the dependences of the cutting ability of the bars on their grain size, concentration and type of binder, the value of ψ is determined empirically from the condition:

$$\psi = \frac{\Delta h_{et}}{L} \quad (12)$$

RESULTS AND DISCUSSION

According to the scheme shown in Figure 2, the following materials were tested: hardened steel 45, HRC 44, ε=32 and raw steel 50, HB 188, ε=24.

According to the methodology, they slide over the surface of the bars ACB 250/200 - M1 - 100%, ACB 315/280 - MP1 - 100% and ACK 400/315 - M1 - 100%, varying from 0.4MPa to 2.8MPa.

Figure 3 shows the results of experiments on the sliding of specimens of steel 50 with a diameter of 4 mm on bars ACB 250/200 - M1 - 100%, ACB 315/280 - MP1 - 100% and ACK 400/315 - M1 - 100%, from which implies that up to a certain value (critical) the dependence of Δh on Py is linear.

In this case, for ACB 250/200 - M1 - 100% critical value P_y=0.6 MPa, for ACB 315/280 - MP1 - 100% P_y=2.0 MPa and for ASV 400/315 - M1 - 100% P_y=2.4 MPa, then there is in these conditions a clean contact of the bar with the treated surface is maintained.

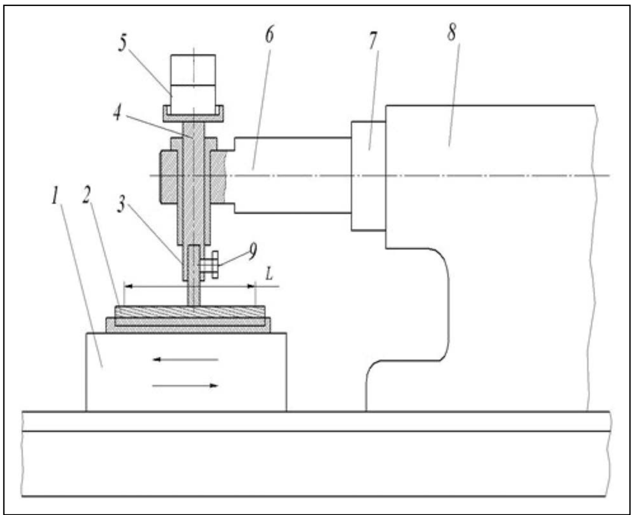

Figure 2. Installation diagram for determining the cutting ability of diamond honing stones: 1 – slide; 2 – diamond bar; 3 – processed sample; 4- rack; 5 – loads; 6 – mandrel; 7 – movable sleeve; 8 – tailstock; 9 – screw stop; L – length of the sliding path on the abrasive surface.

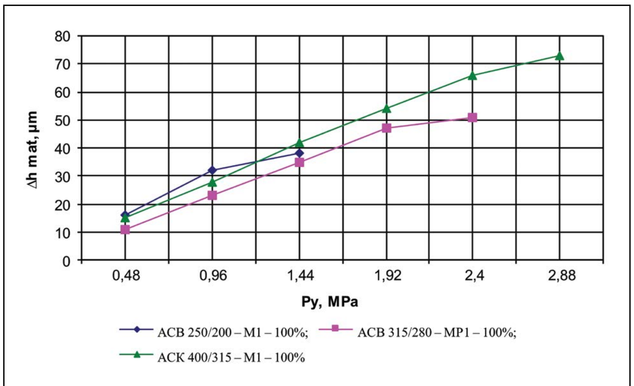

Figure 3. Dependence of linear removal on pressure during sliding of a 50 steel specimen with a hardness of HB=188 on an abrasive surface.

Similar data are shown in Figure 4, for hardened steel 45. Based on the results of the experiments carried out, it can be concluded that the bars on the MP1 bond have a significantly lower cutting ability than on the M1 bond when honing steel 45 and steel 50.

With the same bundles, the larger the grain, the higher the critical value of P_y. Thus, knowing the size and number of bars, it is possible to determine the volume of removed material, taking into account their overrun.

The fundamental difference between this calculation scheme for honing tapered holes is the difference between the contact area of the cutting surface and the peripheral speed for larger and smaller diameters.

Then, for the uniformity of linear wear along the length of the bar, it is necessary to perform it in a trapezoidal shape. Assuming that, all other things being equal, wear is proportional to the volume or linear material removal, the trapezoidal shape of the bars provides this condition.

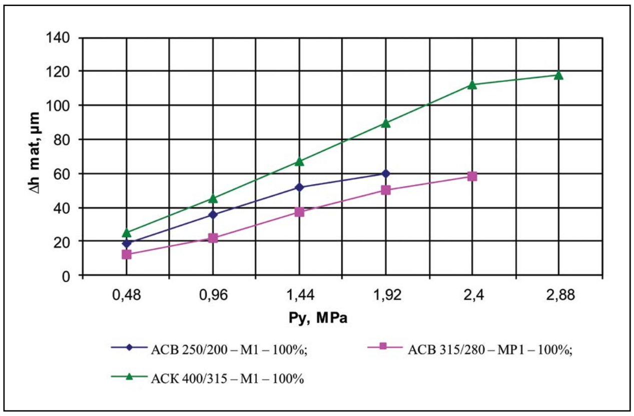

Figure 4. Linear removal versus pressure during sliding of a 45 steel specimen with a hardness of HRC=44 over an abrasive surface.

Research data on the performance of diamond honing stones show that their cutting properties, with correctly selected operating modes during the entire operation of the stone, remain constant and do not require dressing. To do this, it is necessary to withstand the conditions of pure sliding of the bar on the treated surface, which is characterized by a linear dependence of the removal Δh_{mat} from P_y.

This requirement can be met by cleaning the cutting surface of the bars from wear debris, which is ensured by compliance with the accepted honing regimes and the correct choice of cutting fluid.

The contact width of the bar changes as it moves from the end of the smaller hole diameter to the section in which the contact width is considered.

The area of the working surface of the bar F_c, when moving from a smaller diameter to a larger one, constantly changes. Moreover, at the moment of complete overrun of the bars from the larger diameter of the hole, the contact area is minimal and at constant P_y, according to the condition of equality (1), the specific pressure reaches its maximum value.

From equations (5) and (9), we can write that:

$$\eta = \frac{P_z}{P_y} \quad (13)$$

$$P_z = \eta \cdot P_y \quad (14)$$

that is, a constant change in the normal force Fy leads to an oscillation of the tangential forces Fz.

In addition, the change in the tangential forces in individual groups of grains is carried out in different ways, depending on the location of the grains on the surface of the bar. Grains closer to the edge of the bar are less embedded in the material than grains in the middle. Consequently, the forces Pz on the grains are also different and proportional to the depth of their penetration. However, for the grains in the middle part of the rod, it is necessary to comply with the conditions of clean contact (without contact of the bond with the treated surface).

CONCLUSION

In the process of tapered honing, the P_y value changes, which should not go beyond the limits of the clean contact. Otherwise, contact of the bond with the treated surface can cause gripping and a sharp increase in roughness.

The obtained patterns of force dependencies during conical honing make it possible to choose the correct method of radial feed of the bars and determine the exact value of their overruns. These process parameters are the most important in determining the machining accuracy when honing tapered holes.

Data Availability Statement

All graphs and data obtained or generated during the investigation appear in the published article.

Author's Contributions

Esreb Dzhemilov: Drafted and wrote the manuscript, performed the experiment and result analysis.

Ruslan Dzhemalyadinov: Assisted the experiment's progress and helped in manuscript preparation.

Eskender Bekirov: Assisted the experiment's progress and helped in manuscript preparation.

Confilict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics

There are no ethical issues with the publication of this manuscript.

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