



# Research of Treatment Process of Conical Holes by Diamond Honing

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## Abstract

The article discusses the process of finishing machining parts with conical holes, diamond honing. The features of the processing process under study are revealed and its differences from cylindrical honing are determined. Conical surfaces honing occurs with a variable contact width of the working surface of the tool with the workpiece, which leads to uneven material removal. According to the developed method based on tensometry, the nature of the distribution of contact pressures of the interaction of the working surface of the tool with the workpiece is determined. Based on the analysis of the results obtained, an experimental design of the honing head for processing conical holes is proposed. Studies have shown that when processing with an experimental tool, equalization of contact pressure is observed. The resulting effect can be associated with the uniform introduction of cutting grains, regardless of the width of the contact. The calculated values of the contact pressures and the contact width of the tool with the surface of the conical hole are also presented according to the formulas obtained during the research. Based on the results obtained, the deformation coefficient is determined as the ratio of the experimental and calculated contact widths in a certain cross section. Introduction to the calculation formula of the deformation coefficient allows you to establish the width of the contact bar with the generatrix of the conical hole of the workpiece more accurately.

**Keywords:** *Diamond Honing, Conical Holes, Contact Pressure, Tool's Contact Width with the Unit, Strain Factor.*

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## 1. Introduction

To obtain parts with high purity classes and surface quality, the layer is removed with low cutting speeds and very small cut sections (honing, super finish, lapping, lapping, etc.), which significantly reduces the contact temperature and thereby eliminates its effect on structural transformations, deformation of the surface layers of the part, the occurrence of internal stresses and other surface defects.

The destruction of machine parts during their operation usually begins in the upper layers of the working surfaces, since these layers are in the most adverse conditions. Therefore, the characteristics of these layers significantly affect the dynamic and corrosion-mechanical strength, dimensional and shape stability during operation, contact strength, fatigue resistance and other properties of parts.

For given operating conditions, there is an optimal combination of surface properties (roughness, hardening, residual stresses, structure), which provides the most favorable operational characteristics of machine parts. Achieving this combination is possible not only with technological solutions, which

in the first place include the justified purpose of the methods and modes of finishing parts, but also design (a reasonable choice of structural elements and material, the assignment of requirements for accuracy and quality of surfaces).

Recently, numerous statistical and experimental studies have been conducted based on the development and analysis of experimental methods for determining the influence of cutting parameters on surface roughness during honing. Ertugrul and Chinar [1] experimentally investigated the influence of some design and operational parameters on oil consumption and engine performance in a four-stroke diesel engine. In this experimental study, the effects of cylinder surface roughness, the honing angle, and the oil ring on oil consumption and engine performance were selected as honing characteristics. The authors in work [2] indicated that the level of oil consumption for fuel consumption is higher in accordance with industry standards due to deep traces on cylindrical surfaces. In addition, it was found that a 45° honing angle obtained using a honing process using fine grain size honing stones reduces oil consumption.

Corral [3] investigated the influence of various parameters during rough grinding on surface roughness and material removal rate using CBN abrasives. The author showed that the most influential factors are grain size, pressure and abrasive density on roughness, as well as grain size and pressure, followed by a tangential velocity at the material removal rate. Optimum Ra is achieved with the smallest grain size, pressure and maximum density, tangential velocity and linear velocity.

Troglio [4] studied the effect of abrasive grain size, lubricating oil, and workpiece material on roughness parameters Ra or Rk. In addition, the author investigated the effect of honing parameters on roundness and cylindricity. Tool wear, power consumption, material removal rate and specific energy after the honing process for three different materials were also determined.

Corral and Calvette [5] used steel cylinders for honing using CBN tools to determine the change in roughness. The results showed that the roughness of the cylinders increased mainly with the size of the abrasive grain, after which the head pressure was honed, while the tangential velocity had a slight effect on the roughness.

Bai and Zhang [6] investigated the variability of pressure, speed, and cross-hatching angle in order to increase the efficiency of the honing process performed with a honing stone with a grain size of 220. The highest material removal rate was achieved with a cross-hatching angle between 40° and 60°.

As another Corral study, [7] introduced a new technique for determining the rate of material removal during honing of St-52 steel cylinders. The cylinders were honed under various conditions, such as grain size and number of strokes, to determine the accuracy of the probabilistic parameters. The results showed that the difference in the area of the Abbott-Firestone curve for rough honing and fine honing is proportional to the material removal rate in the finishing operation.

Sivatt [8] performed an indirect roughness model in rough honing processes of St-52 steel cylinders with different honing parameters depending on the required Ra. It was indicated that surface roughness increases with increasing grain size and density according to experimental results based on the Taguchi method. The indirect model showed about 85% of the confirmation of the experimental results, so the author came to the conclusion that the model is considered verified.

Silva [9] applied particle swarm optimization to achieve minimal profile error when honing SAE 4320-H steel. Gear parts were used as blanks to test optimization techniques. From the optimization it was determined that the optimum feed rate in the X direction was from 1,5 to 5,7 μm/min, and the optimal feed rate in the Z direction was from 100 to 600 mm/min. The result also showed that the ideal spindle speed was 4000 rpm in accordance with optimization tests.

Lawrence [10] studied the process of processing cylinder liners in an automobile engine to develop a working level of parameters for roughing and finishing honing.

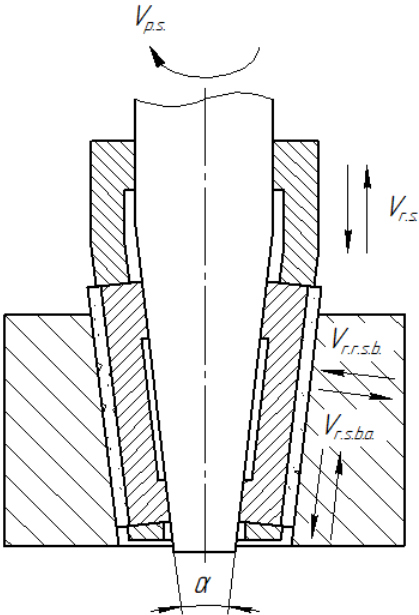
Pawlus [11] used diamond abrasive bars in his studies to hone the cast iron cylinders of diesel engines. In the experiments, various levels of working pressure and honing time were used, while the grain size remained constant 151, 76 and 15 during roughing, semi-finishing and finishing operations, respectively. The study correlates between the roughness parameters associated with the Abbott-Firestone curve and the probability curve. They confirmed linear independence and stability of probabilistic parameters. This study was aimed at optimizing honing parameters such as linear speed, grain size and number of strokes for surface roughness on honing a plateau of cast iron cylinder block. First, the Taguchi method was used to achieve this. Secondly, analysis of variance in order to determine the significance level of honing parameters and optimization studies was performed with a confidence probability of 95%.

Studies of many authors of diamond honing problems are mainly devoted to the processing of cylindrical and partially flat and spherical surfaces.

One of the effective directions for further expanding the scope and more fully utilizing the technological capabilities of the diamond honing process is its use in the processing of precise conical surfaces. Known operations that form conical holes do not provide a stable quality of the machined surfaces. The study of the mechanics of the contact interaction of a diamond tool with a part is a promising direction in the field of research and scientific forecasting of improving the quality of diamond processing.

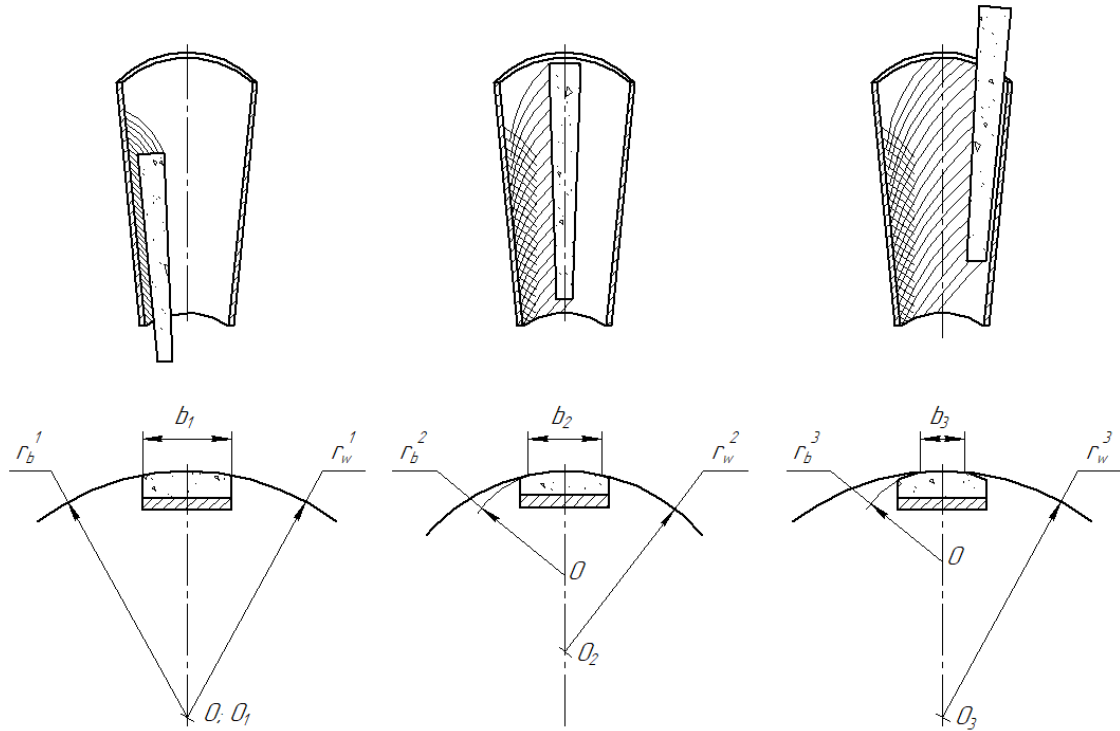
**2. Theory**

In the kinematics of the process of honing a conical hole (Figure 1), there are four main movements relative to the part: a combined cutting movement - rotational  $V_{p.s.}$  (m/min) and reciprocating  $V_{r.s.}$  (m/min); combined movement of the bars - radial reciprocating movement of the bars  $V_{r.r.s.b.}$  (m/min) and the reciprocating motion of the bars along the generatrix  $V_{r.s.b.a.}$  (m/min) (to ensure constant contact of the working surface of the tool with the part). After each double stroke of the tool, the dosed supply of  $S_{rad}$  bars ( $\mu\text{m}/\text{double stroke}$ ) is carried out.



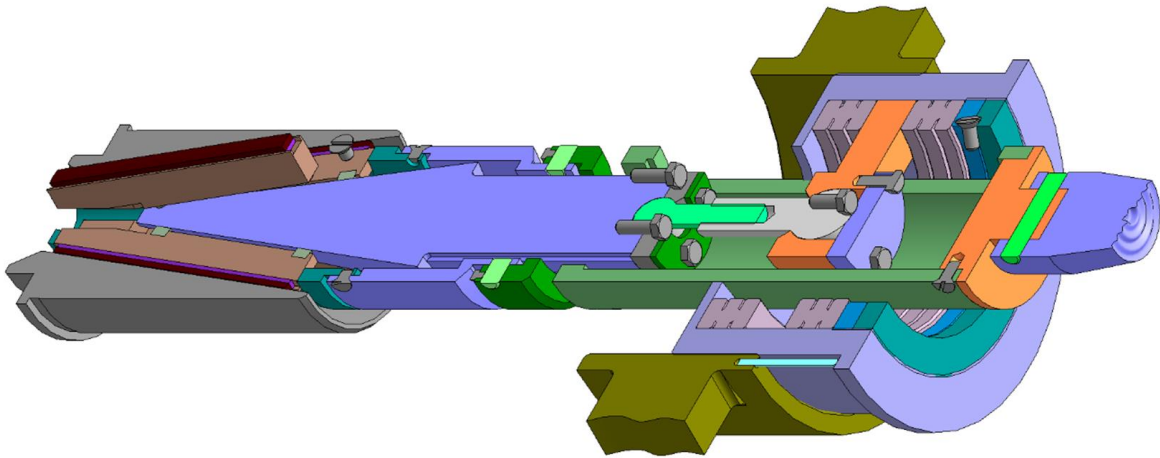
**Figure 1.** Scheme of working movements in conical honing

The process of processing conical holes with diamond honing proceeds with a variable contact width of the working surface of the tool with the workpiece, which leads to uneven material removal (Figure 2). The change in the contact width of the bars depends on the angle of the cone of the hole being machined and the stroke length of the tool [12].



**Figure 2.** Scheme of changing the contact width of the tool working surface with the part

According to the developed methodology, based on tensometry, studies have been carried out of the contact interaction of the working surface of an industrial construction tool with a part. It was found that with a decrease in the width of the contact, the contact pressure increases. Based on the results obtained, the design of a honing head is proposed (Figure 3), which ensures uniform material removal due to equalization of contact pressures [13].



**Figure 3.** Honing head for machining conical holes

### 3. Results and Discussions

The results of the distribution of contact pressures along the working surface of the AC6 500/400-M5-01-100% diamond bar when machining a billet of steel 40X (analogue 41 Cr4) and axial load  $P_y = 72$  N, obtained experimentally and calculated are presented in Table 1.

**Table 1.** Values of contact pressures on the bar surface

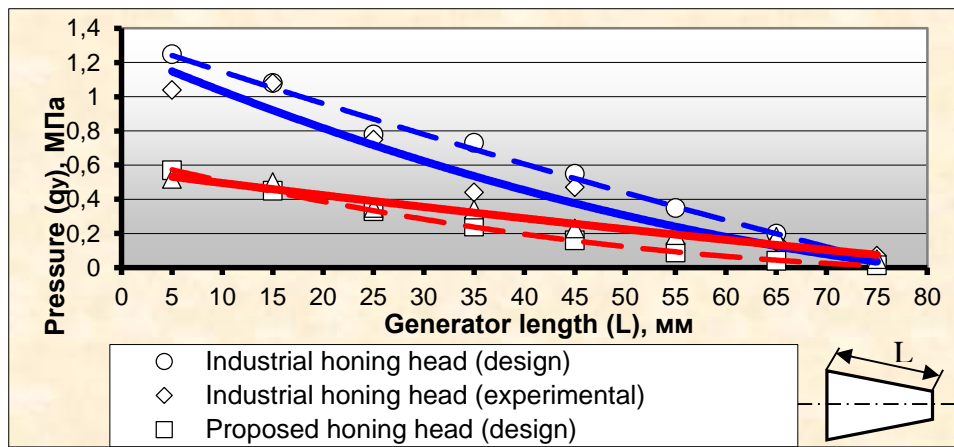
Length forming (L), mm	Contact pressure ( $q_y^{\max}$ ), MPa			
	Industrial block		Proposed block	
	Experimental	Estimated	Experimental	Estimated
5	1,04	1,25	0,52	0,57
15	1,08	1,18	0,50	0,45
25	0,75	0,78	0,35	0,33
35	0,44	0,73	0,34	0,24
45	0,47	0,55	0,23	0,16
55	0,10	0,35	0,19	0,09
65	0,15	0,20	0,18	0,04
75	0,07	0,04	0,05	0,014

In Table 1, the calculated values of contact pressures were determined by the Formula (1) [14, p.62]:

$$q_y^{\max} = \beta \cdot \omega \cdot k_d^2 \cdot HV \cdot \bar{N} \cdot \delta_{\max}^2 \quad (1)$$

where  $\beta$  - is a coefficient depending on the shape of the cutting grain;  $\omega$  - is a coefficient taking into account the difference between the shape of the grain and the shape of the Vickers pyramid;  $k_d$  - is the dynamics coefficient taking into account the decrease in the depth of grain penetration during cutting (established experimentally); HV - Vickers hardness of the processed material;  $\bar{N}$  - the number of grains involved in cutting;  $\delta_{\max}$  - maximum introduction of cutting grain.

Based on the obtained values of contact pressures, the dependences of the distribution of contact pressures along the working surface of the bar are plotted (Figure 4).



**Figure 4.** Distribution of contact pressures during the interaction of the tool working surface with the part

The obtained results of the contact pressure studies allow us to develop recommendations on the design of a tool that ensures the quality of processing a conical hole.

The magnitude of the contact pressure depends on the width of the contact of the diamond bar with the surface of the conical hole  $b_k$ . The contact width of the AC6 500/400-M5-01-100% diamond bar with the surface of the conical hole was calculated using the Formula (2) [14, p. 49]:

$$b_k = 2\sqrt{2} \sqrt{\frac{r_w \cdot r_b}{r_w - r_b} \cdot \delta_{\max}} \quad (2)$$

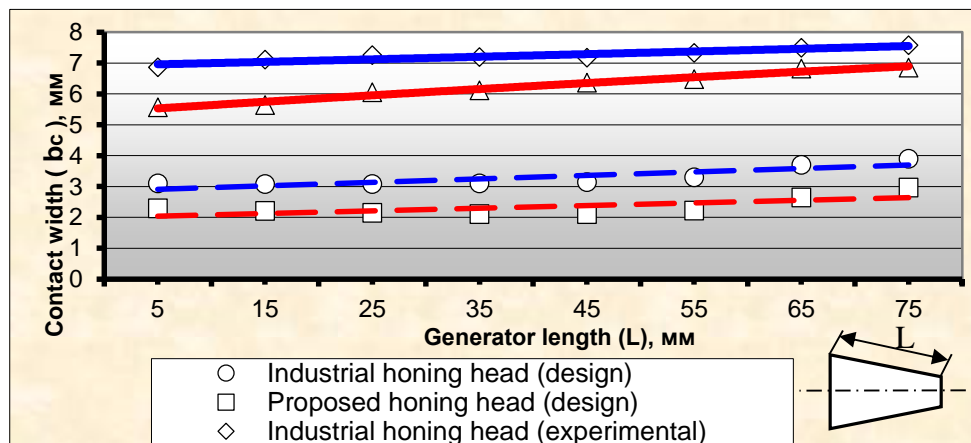
where  $r_w$  and  $r_b$  - are the radius of the conical hole of the workpiece and the radius of the bar in a certain cross section, respectively;  $\delta_{\max}$  - is the maximum penetration depth of diamond grains.

To clarify the Formula (2), the contact width was experimentally determined. The calculated and experimental values of the contact width are shown in Table 2.

**Table 2.** The contact width of the diamond bar AC6 500/400-M5-01-100% along the length of the generatrix of the conical hole of the workpiece

Length Forming (L), mm	Grain Depth ( $\delta$ ), $\mu\text{m}$		Contact width ( $b_k$ ), mm			
	Industrial block	Proposed block	Industrial block		Proposed block	
			Experimental	Estimated	Experimental	Estimated
5	9,65	5,27	6,86	3,1	5,57	2,29
15	8,57	4,40	7,11	3,08	5,64	2,21
25	7,45	3,62	7,26	3,08	6,05	2,15
35	6,31	2,92	7,19	3,1	6,12	2,107
45	5,12	2,31	7,17	3,14	6,36	2,11
55	3,89	1,79	7,33	3,3	6,48	2,22
65	2,64	1,35	7,49	3,7	6,82	2,65
75	1,39	0,82	7,58	3,9	6,85	2,97

Based on the results obtained, the dependences of the contact width of the diamond bar along the generatrix of the conical hole are constructed, which are presented in Figure 5.



**Figure 5.** The dependence of the contact width of the bar along the generatrix of the conical hole

Such a difference between the experimental and calculated results of the width of the contact of the bar with the generatrix of the conical hole is due to the fact that the processes of elastic-plastic deformation are not taken into account in Formula (2).

Using the results obtained, it is possible to determine the coefficient  $k_{def}$ , which takes into account the deformation, the introduction of which in Formula (2) will more accurately establish the contact width of the bar with the generatrix of the conical hole of the workpiece  $b_k$ . The value of  $k_{def}$  depends on the mechanical properties of the material, the size and shape of the workpiece, as well as on the characteristics of the bar and the design of the pads.  $k_{def}$  is defined as the ratio of the experimental and calculated contact widths in a specific cross section. Table 3 shows the values of the strain coefficients for the contact conditions listed in Table 1.

**Table 3.** The values of the strain coefficients  $k_{def}$

Length Forming (L), mm	5	15	25	35	45	55	65	75	
Strain factor $k_{def}$	Industrial block	2,21	2,31	2,36	2,32	2,28	2,22	2,02	1,94
	Proposed block	2,43	2,55	2,81	2,9	3,01	2,92	2,57	2,31

Thus, the contact width formula  $b_k$  will take the following form:

$$b_k = 2\sqrt{2} \cdot k_{def} \sqrt{\frac{r_w \cdot r_b}{r_w - r_b} \cdot \delta_{max}} \quad (3)$$

#### 4. Conclusion

Studies have shown that the alignment of contact pressures on the tool working surface contributes to the uniform introduction of cutting grains regardless of the contact width.

The obtained effect contributes to the formation of a conical hole of high accuracy and uniform roughness in the workpiece over the entire machined surface.

The introduction of the proposed tool in machine-building enterprises will make it possible to ensure tightness in parts having conical joints and operated under high pressure.

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