Technology of magnetic-abrasive finishing of geometrically-complex products

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Abstract. The present article considers the possibilities of magnetic-abrasive finishing technology with regards to increasing the quality of geometrically-complex products. The experimental research on magnetic-abrasive finishing technology which resulted in obtaining mathematical relation is described and the influence of technological factors of magnetic-abrasive finishing on the quality of the surface layer of geometrically-complex products are revealed. It was stated that the product edge radius alters within the scope of \( \rho = 26…64 \) \( \mu \)m, roughness within the scope of \( Ra = 0.09…0.61 \) \( \mu \)m, and micro-hardness within the scope of \( Hv = 766…1505 \) kgf/mm\(^2\) in the range of technological factors of magnetic-abrasive finishing under study.

1. Introduction
The major issue of mechanical-engineering technology in modern times is to improve the quality of the surface layer of a product being manufactured, while the quality influences the functional properties of the product during its further use. Under these circumstances, products with geometrically-complex surfaces gain significant importance because the process of their manufacturing is complicated by their curved space form [4].

Cutting tools, including tapping tools, can refer to geometrically-complex products. The state of the surface layer of the contact surface of tapping tool’s teeth specifies not only the given product capacity but also the quality of lateral sides of the inner tapped profile, which is formed by means of this state.

It is known from the theory and practice of mechanic engineering that the tapped profile is formed by transferring the form of cutting teeth onto the product. Herewith, qualitative characteristics and flaws are automatically copied from the surface of teeth to the surface of the product being manufactured. A cutting edge and a zone close to it [1, 5] are of crucial significance in this respect while it is the greatly loaded part of a V-shaped tooth. This aspect is confirmed by the fact that 95% of all refusals at the enterprises are caused by edge defects. Consequently, the improvement of quality of the surface layer of cutting edges of a product (tapping tool) is a relevant research-and-engineering issue of modern mechanic engineering.

Nowadays, it is stated [1, 2, 5] that cutting edges of tools should be subjected to additional final finishing after grinding. It stems from the fact that final operations enable rounding the cutting edges up to the required values, decreasing their micro geometry and form a strengthening layer on them, which will have positive impact on a tool’s performance characteristics.

The analysis of the existing finishing operations applied for geometrically-complex surfaces has shown that the most efficient process for accomplishment of such objectives is magnetic-abrasive finishing (MAF) technology. MAF technology is represented in Figure 1 and lies in the following: the powder ferromagnetic...
abrasive mass having been thickened by magnetic-field energy has an abrasive influence on a workpiece [3]. Herewith, the workpiece is subjected to specific motions required for the processing: rotational, oscillatory and to-and-fro (if possible) motions.

The required quality of a surface layer (radius of rounding, roughness, micro-hardness) of cutting edges of a tapping tool under the circumstances of the best possible operating parameters of MAF process should be achieved on the basis of main regularities of the experimental variables changing with regards to the conditions of magnetic-abrasive finishing. Against this background, one can state that the objective of the present research is to specify the regularities and dependences of MAF process technological factors with regards to the qualitative parameters of tapping tool cutting edges.

2. Materials and methods

A tapping tool magnetic-abrasive finishing was carried out on a specifically developed aggregate located in the Laboratory of CNC machines on the basis of Department of Mechanic Engineering, St. Petersburg Mining University. The aggregate for MAF was based on a CNC mill, which enables one to provide the treatment process by all required working motion [6-8].

Tapping tools M16×2 made of quick-cutting steel P6M5 were used as workpieces. Powder with a titanium and iron carbide (TiC+Fe) base was used to form a magnetic-abrasive brush in the electromagnetic system operating space. Varying parameters were introduced by MAF technological factors: powder grain size $\Delta = 160…315$ $\mu$m; magnetic density $B = 0.6…1.0$ T; finishing time length $t = 60…210$ sec. The testing parameters were as follows: the cutting edges rounding radius $\rho$, $\mu$m; cutting edges roughness and micro-hardness $Ra$, $\mu$m and $Hv$, kgf/mm$^2$ respectively.

The radius of rounding and roughness of the tapping tool’s cutting edges was monitored by means of profilograph-profilometer Hommel Tester T8000; micro-hardness was tested with the PMT-3M micro-hardness tester; visual examination of contact surface conditions of tapping tool’s teeth was carried out through the use of measuring microscope MarVision MM320.

3. Outcomes of experimental research and their discussion

3.1. Mathematical relation of the impact of MAF process technological factors on the testing parameters.

Evaluation of test data resulted in deducing mathematical relations enabling to determine radius of rounding, roughness and micro-hardness of tapping tool’s cutting edges in terms of technological factors of the MAF process being powder grain size, magnetic density, finishing time length. The deduced mathematical relations are as follows:

1. Influence of technological factors MAF on the cutting edges radius of rounding:

   $$ \rho = 0.988 \cdot \Delta^{0.51} \cdot B^{0.4} \cdot t^{0.23}. $$

2. Influence of technological factors MAF on the cutting edges roughness:

   $$ Ra = 0.197 \cdot \Delta^{-0.077} \cdot B^{-0.153} \cdot t^{-0.13}. $$

3. Influence of technological factors MAF on the cutting edges micro-hardness:

   $$ Hv = 141.599 \cdot \Delta^{0.139} \cdot B^{0.455} \cdot t^{0.279}. $$

The analysis of presented mathematical relations enables one to conclude that powder roughness poses the major impact on the size of the cutting edges radius of rounding while magnetic density significantly influences the cutting edges roughness and micro-hardness.

![Figure 1. Magnetic-abrasive finishing technology: 1 is a workpiece; 2 – magnetic-abrasive powder; 3 – pole-shoes; 4 – magnetic coils](image-url)
3.2. *The impact of MAF process technological factors on the cutting edges radius of rounding.*

Figure 2 demonstrates the dependences of the alterations of tapping tool’s cutting edges rounding radius on technological factors of MAF process.

![Figure 2](image)

**Figure 2.** Distribution of tapping tool’s cutting edges rounding radius values in spaces: “tapping tool’s cutting edges rounding radius – powder grain size – finishing time length” (a); “tapping tool’s cutting edges rounding radius – magnetic density – powder grain size” (b)

The demonstrated dependences carry several inferences. Firstly, the cutting edges rounding radius increases with the reduction of powder grain size, magnetic density and finishing time length. Notably, the cutting edges rounding radius increases due to enhancing the cutting capability of magnetic-abrasive mass. As a result, large surpluses (in comparison with smaller grading fraction) are removed from the tapping tool teeth. Secondly, stiffness of magnetic-abrasive brush and forces applied to the grains processed by a tapping tool increase with the growth of magnetic density, which results in greater cutting edges dulling. Thirdly, finishing time increment causes the increased period of the impact of magnetic-abrasive mass on the V-shaped area of tapping tool’s teeth, which as well as in two previous cases leads to the increase of the cutting edges’ rounding radius.

The values of the cutting edges’ rounding radius of the tapping tool within the range of MAF factors under study alter within the scope of $\rho = 26…64 \, \mu m$.

3.3 *The impact of MAF process technology factors on the cutting edges roughness.*

It is well-known that the tool’s cutting edge as well as a cutting edge of any other object is the result of the intersection of two surfaces [5], whose roughness alters (deteriorates) in the course of interaction between a tool and a workpiece. When cutting a screw thread with a tapping tool, the most significant roughness occurs at rear surfaces. Roughness deterioration at rear surfaces comes along with extensive wear of the work materials, which exert a significant impact on the profile accuracy of the thread being cut and result in cleavages and microchipping of cutting profiles and tapping tool breakdowns. Consequently, the present research gives special consideration to the tapping tool cutting edges rear surfaces roughness.

3.3.1 *Comparative analysis of the profilographs of cutting edges’ rear surfaces before and after MAF.*

Figure 3 demonstrates a profilograph of the roughness of the rear surface of the 4th tooth of the cutting part of a tapping tool before and after magnetic-abrasive finishing. Major change of microshape surface during a relatively small timespan indicates prospects of applying magnetic-abrasive finishing technique to solve the problem of surface layer quality improvement.
а) б)

**Figure 3.** Profilographs of roughness of rear surface of the 4th tooth of the cutting part of a tapping tool: a) before MAF (Ra = 0.34 µm); b) after MAF (Ra = 0.06 µm); finishing conditions: Δ = 315 µm; B = 1.0 T; t = 210 sec; δ = 1 mm.

Profilographs comparative analysis enables one to conclude that the roughness of the rear surfaces of cutting tools alters within the scope of technological factors and under the conditions of low MAF from 0.22 µm to 0.09 µm with regards to parameter Ra, and from 0.28 to 0.06 µm (Ra values are the arithmetic average along all measured surfaces of tapping tool’s teeth) against the background of supreme machining conditions.

### 3.3.2 The impact of MAF process technological factors on the cutting edges rear faces roughness.

Figure 4 demonstrates the dependences of the roughness of rear faces of the tapping tool’s cutting edges on the technological factors of MAF process.

а) б)

**Figure 4.** Distribution of roughness values of rear faces of tapping tool’s cutting edges in spaces: “cutting edges roughness – powder grain size – finishing time length” (a); “cutting edges roughness – magnetic density – powder grain size” (b).

The demonstrated dependences carry several inferences. Firstly, the tapping tool’s cutting edges rear faces roughness alters within the scope of Ra = 0.09…0.061 µm. Secondly, the increase of the finishing time length, magnetic density and powder grain size comes along with the decrease in surface roughness, which is conditioned by deleting primary microroughnesses of the work surface with magnetic-abrasive powder.

Due to the fact that primary microroughnesses of the rear surfaces of cutting edges are as follows: Ra = 0.22 µm, the fundamental deleting of microroughnesses is carried out within initial 60 seconds of processing. A further microroughness diminishing is rather sustainable. Intensive roughness reduction during the first seconds of finishing can be caused by the situation when the magnetic-abrasive powder...
grains, whose size is larger than the roughness primary width, exert the initial significant impact on the roughness protrusion and remove them in a more intensive way than wide slots. In the course of removing initial tips and a defective layer prone to destruction and forming a hardened layer under the influence of MAF itself, roughness lowering slows down. This characteristic feature can be seen in the presented dependences, built subsequently to the results of experimental research on magnetic-abrasive finishing of a tapping tool.

3.4 The impact of MAF process technological factors on the cutting edges rear faces micro-hardness.

Micro-hardness as well as roughness was studied on the rear faces of tapping tool’s cutting edges. Figure 5 presents the dependences of the micro-hardness of rear faces of the tapping tool’s cutting edges on the technological factors of MAF process.

![Figure 5](image.png)

**Figure 5.** Distribution of micro-hardness values of rear faces of tapping tool’s cutting edges in spaces: “cutting edges micro-hardness – powder grain size – finishing time length” (a); “cutting edges micro-hardness – magnetic density – powder grain size” (b)

The demonstrated dependences carry several inferences. Micro-hardness of the rear faces of tapping tool’s cutting edges increases within the scope of the range of MAF process technological factors under study with increase in processing time, magnetic density and powder grain size, which is conditioned by the surface layer hardening due to the influence of both magnetic and mechanic fields. Micro-hardness of the cutting edges’ rear faces in this case alters within the scope of $H_v = 766...1505$ kgf/mm$^2$.

3.5 Visual examination of contact surface conditions of tapping tool’s teeth.

The issue of removing the initial defective layer under various conditions of magnetic-abrasive finishing is of special interest. In view of this, contact surface conditions of tapping tool’s teeth before and after MAF (Figure 6) in terms of diverse technological, factors were visually examined and their comparative analysis was conducted as well.
Comparative analysis of contact surfaces of tool teeth of the tapping processed in different conditions of MAF enables one to conclude that the major defects frequently observed on cutting edges can be fully eliminated by means of magnetic-abrasive finishing within the $t = 210$ sec. period of processing regardless of the induction value and powder grain size (the range under study). Furthermore, it can be partially eliminated under the conditions of $t = 120$ sec. period of processing and practically cannot be ever eliminated as a result of $t = 60$ sec. period of processing when the powder grain size is $\Delta = 315 \mu m$ and magnetic density is $B = 1.0$ T.

4. Conclusion

The conducted research with the application of technology of magnetic-abrasive finishing of geometrically-complex products resulted in deducing mathematical dependences and revealing regularities of the impact of MAF process technological factors on the qualitative parameters of tapping tool’s cutting edges (rounding radius, roughness, micro-hardness). It was stated that the rounding radius of cutting edges alters within the following boundaries: $\rho = 26...64 \mu m$, roughness – within the boundaries $Ra = 0.09...0.061 \mu m$, and micro-hardness – $Hv = 766...1505$ kgf/mm$^2$ within the range of technological factors of MAF process under study. Visual examination of contact surfaces of tapping tool’s cutting teeth allows deducing that the defects frequently observed on cutting edges can be fully eliminated by means of magnetic-abrasive finishing under particular machining conditions.

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