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Technology of high-speed combined machining with brush electrode

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Abstract. The new method was proposed for high-precision dimensional machining with a brush electrode when the true position of bundles of metal wire is adjusted by means of creating controlled centrifugal forces appeared due to the increased frequency of rotation of a tool. There are the ultimate values of circumferential velocity at which the bundles are pressed against a machined area of a workpiece in a stable manner despite the profile of the machined surface and variable stock of the workpiece. The special aspects of design of processing procedures for finishing standard parts, including components of products with low rigidity, are disclosed. The methodology of calculation and selection of processing modes which allow one to produce high-precision details and to provide corresponding surface roughness required to perform finishing operations (including the preparation of a surface for metal deposition) is presented. The production experience concerned with the use of high-speed combined machining with an unshaped tool electrode in knowledge-intensive branches of the machine-building industry for different types of production is analyzed. It is shown that the implementation of high-speed dimensional machining with an unshaped brush electrode allows one to expand the field of use of the considered process due to the application of a multipurpose tool in the form of a metal brush, as well as to obtain stable results of finishing and to provide the opportunities for long-term operation of the equipment without its changeover and readjustment.

1. Introduction
The contemporary production industry with a flexible structure requires application of multipurpose tools and the most suitable technologies for this are non-traditional electrophysical and electrochemical ones which stipulate the use of an unshaped tool electrode that can be made in the form of a rigid rod, a stretched wire, or an electrode-brush with a working part consisting of cantilevered wire. Most of the studies carried out in this area are related with the dimensionless formation of a good-quality surface layer, but they do not solve the main issue, i.e. dimensional machining of high-precision details with complex shape, especially produced from difficult-to-machine alloys. The further development of this promising technological direction (combined methods of processing with the application of electric field) became possible only after the investigation and implementation of the procedure of the high-speed (the speed at the periphery of a disk tool is more than 35 m/sec) dimensional finish form-making of various surfaces with a multipurpose unshaped tool electrode (brush electrode), as well as due to the development of the methodology of the design of
technological processes and technological equipment for dimensional processing with the provision of technological indicators which are not lower than those achieved in machining.

2. **Special aspects of high-speed machining with a brush electrode**

One of the promising methods of machining with an unshaped tool is machining with an unshaped brush electrode [1] with a working part consisting of cantilevered thin wire which is widely used in various industrial branches, especially in the aerospace industry. Figure 1 shows the scheme of machining with an unshaped brush electrode.

![Figure 1. The scheme of machining with a disk brush: 1 - machine table, 2 - machined workpiece, 3 - brush electrode, 4 - nozzle to supply working fluid 5.](image)

Brush electrode 3 rotates at speed \( \omega \). The workpiece with a given feed of \( S \) moves to the brush electrode. The machining is carried out with the supply of direct current up to 12 V to tool 3 and workpiece 2. Brush electrode 3 comprises radial bundles of thin wire mounted on the central disk and spaced several millimeters apart. During machining, the ends of the bundles periodically touch the surface of workpiece 2 and are pressed against the workpiece. The performance characteristics of the process depend on the pressing force and its stability which is affected by the position of the bundles: the closer they are situated to the radial position, the more stable the process is. This is achieved by the action of centrifugal forces during the high-speed rotation of the brush electrode proposed in [1, 2, 3].

3. **Design of brush electrodes**

High-speed machining can be carried out with disk, cup, or combined brushes or thin ones both on specially designed and modernized multipurpose metal-cutting machines equipped with power supply units.

The brush electrodes with a working part made of steel, copper M1, or brass L80 wire with the diameter of 0.02-0.2 mm are used as an unshaped tool. Machining is carried out at circumferential speed \( \omega \) (Fig. 1) up to 60 m/s and the pressing of the ends of wire to the workpiece up to 0.6 mm.

The most interesting electrodes are those mentioned in [4] which have the form of a thin brush (Fig. 2) and are used to eliminate burrs and to round edges in intersecting channels inside holes with a small diameter.
The left part of Fig. 2 shows the thin brush electrodes in operating condition where wire bundles are moved apart due to the action of centrifugal forces and internal stresses and they can be located in the position close to the radial one. The external diameter of such electrodes is limited by the position of the ring on the surface of the bundles (the central part of Fig. 2). The right part of Fig. 2 shows the shape of the bundles tightened with the ring which allows one to approach the tool to a machining area through holes with small diameter.

4. Calculation of a working profile of the brush electrode

The calculation of the external diameter of the most commonly used disk brush is performed assuming that the bundles of wire are straightened due to the action of centrifugal forces, taking into account the pressing force of their ends to a workpiece.

In order to estimate pressing force \( F \), it is necessary to approximate maximally the external profile of the tool to the shape of a machining area of a workpiece that can have various radii \( R \) of the profile roundness which can be characterized by variable parameters. The surface to be machined can have a variable profile.

The diameter of the bushing \( D \) is assigned taking into account fitting diameters of a machine spindle and usually is not calculated.

Then the external diameter \( D_e \) of the tool is as follows:

\[
D_e = 2l_n + D + 2F \leq 2R_1 ,
\]

where \( l_n \) is the length of the wire bundle, \( R_1 \) is the ultimate radius of the disc tool installed on the machine.

Now it is possible to calculate the ultimate length of wire \( l_n \)

\[
l_n = R_1 - F - 0,5D
\]

The width of the brush electrode \( B \) is determined according to the condition that the ends of wire always at least touch a machined surface and clean it for anodic stripping of stock \( \Delta h \).

\[
B \leq 2\sqrt{\Delta h(2R_2 - \Delta h)} ,
\]

where \( R_2 \) is the radius of rounding of a machined profile.
Let us considering that the criterion of the standard operation of the brush electrode is as follows:

\[ F \geq \Delta h , \]  \tag{4}

then:

\[ B = 2\sqrt{F(2R_2 - F)} . \]

This allows one to determine the section of bundles for machining workpieces with minimum bend radius (\( R_2 \)) and variation of roughness within the limits of stock (\( \Delta h \)).

The bundles have round section in most cases. The bundle has the minimum diameter at the periphery of the tool, \( D_{n1} = B \).

The bundle expands after it was fixed in the bushing and its diameter \( D_{n2} \) in the point of contact with a workpiece is as follows:

\[ D_{n2} = K_p D_{n1} , \]  \tag{5}

where \( K_p \) is the coefficient of bundle expansion (\( K_p = 1.1 - 1.2 \) depending on \( I_n \) and characteristics of its material).

Taking into account the possibility of fixing the bundles to the sleeve, the number of beams (\( N_n \)) across the width of the brush electrode (\( B \)) is as follows:

\[ N_n \leq \frac{B}{D_{n2}} = \frac{2\sqrt{F(2R_2 - F)}}{K_p D_{n1}} , \]  \tag{6}

where \( N_n \) is an integer number.

5. Methodology of design of the technological process of high-speed machining with a brush electrode

The input data for the design are as follows: a geometric form of a work piece and a machining area with the information about the properties of the material, accuracy and quality of the surface layer, product characteristics, as well as the reference information about the modes of machining with a brush electrode, the labor intensity of the previously accepted processes of performing the similar operations (if any), the limiting capabilities of a machine to increase the peripheral speed of the spindle.

The design procedure includes the following stages:

- Feasibility study for the replacement of the existing option of machining technique (if any) for the proposed one. The design continues if the result is positive.
- Analysis of the geometry of a workpiece and determination of problem areas considering the requirements indicated in the drawing of a workpiece shall be met.
- The calculation of the geometry and dimensions of a brush electrode considering the parameters of problem areas of a workpiece according to the given method.
- Selection and adjustment of technological modes of machining with the provision to meet the technical requirements determined by a designer and to provide stable pressing force for the peripheral part of a brush electrode for machined workpieces of various shape. Machining of the most part of workpieces is recommended to carry out at the voltage of 4-12 V. Pressing force of wire bundles of a brush electrode on the surface of a machined workpiece varies from -0.02 to +0.25 mm. The circumferential speed is 40-60 m/s and higher.
- Adjustment of parameters of tools and machining modes in case of deviations of calculated values beyond the limits allowable for the selected equipment.
- The design [5] of the processing procedure with the assessment of capabilities of available equipment, as well as jigs, fixtures and tools. In case of nonconformity other equipment is selected and
the need for its modernization is determined. Then the design and manufacture of jigs, fixtures and tools (brush electrodes, appliances, etc.) are carried out.

6. Examples of the implementation of high-speed machining with a brush electrode

Machining with a brush electrode is carried out during the manufacture of products of a complex shape, for example to form flanks of gears (Fig. 3).

![Figure 3. The profile of a tooth of a flanked gear](image)

The purpose of high-speed machining is to chamfer the ends of a tooth by h (figure 3) 0.2-0.5 mm longwise (depending on the length of tooth L) while retaining transition radius r and the width of tooth ab. The application of the proposed method allows one to increase the productivity of flank formation and to increase the durability of gears.

Figure 4 shows the standard details after removal of burrs and chamfering. The implementation of high-speed machining made it possible to localize the area of machining and to improve the accuracy of the profile.

![Figure 4. Parts after carrying out high-speed machining with a brush electrode: 1 - aluminum casted body, 2a - welded joint of a stainless steel reservoir before trimming, 2b - welded joint after trimming of edges and places of welding, 3 - piston rings after the removal of microburrs](image)

The implementation of high-speed finish machining allowed one to reduce the imprecision of the transition areas to 3-5 µm and to keep sharp edges near rings (Figure 4-3). The equipment was produced (generally by means of the modernization of grinding machines).

The implementation of high-speed machining in practice demonstrated the possibility to achieve the following performance characteristics: the accuracy is ±0.08 mm; the roughness of the surface layer is up to $R_a = 0.63$ µm and in some cases - up to $R_a = 0.1$ µm; the speed of machining of welded joints is increased to 40 m/min that is an order of magnitude higher than the speed of machining with mechanical and abrasive tools and is accompanied with the reduction of surface roughness to $R_a = 5$ µm.
7. Conclusion
The procedure of high-speed contact combined dimensional machining of current-conducting materials with an unshaped brush electrode is developed. High-speed machining allows one to stabilize the process, to ensure high accuracy and to obtain a good-quality surface layer on a part.

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