Method of determining the axial profile and diameter in various micro-holes’ cross-sections after electrical discharge machining

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Abstract. The paper presents a new method for the assessment of the accuracy of micro-holes obtained by electrical discharge machining, which was called the "blades method" by the authors. This method allows estimating to a high precision the errors in size and shape (taper, ovality) of the holes in the cross-sections of different heights and the axial longitudinal section of the hole. The application of this method is especially effective in studies of the blind micro-holes, as well as non-cylindrical holes, the measurement of which is especially difficult. The developed method was tested in the study of hole profiles processed at different pulse energy. A technological method for EDM of the holes with the help of two modes is proposed, which reduces the main hole shape errors. The application of the developed method allowed increasing significantly the efficiency of studying the electrical discharge machining micro-holes accuracy.

1. Introduction

As the practice of modern mechanical engineering production shows, for the processing of precision micro-holes, the application of the method of electrical discharge machining (EDM) is especially effective. With the development of mechanical engineering, there is a complication of products with micro-holes and an increase in the basic requirements for the accuracy of their manufacture. In this regard, studies aimed at reducing errors arising from EDM processing and increasing the accuracy are currently actual [1–6].

The most common errors of the micro-holes shapes are: in cross sections – ovality (deviation from circularity), in the longitudinal axial section - taper (deviation from cylindricity). The ovality of the hole in the cross-sections occurs due to a deviation from parallelism of the geometric axis of the tool electrode relative to the direction of its supply. The taper of the hole in the longitudinal axial section (increasing the hole’s diameter from the lower cross sections to the upper) is formed due to physicochemical processes in the lateral interelectrode gap: by additional electrical discharges going through the processing products during their evacuation from the interelectrode gap, as well as electrochemical anodic dissolution of the hole surface material [7–12].

In order to research the main shape errors that occur during EDM of micro-holes, in this paper a method for determining the axial profile and hole diameter in various cross-sections, which the authors called the "blades method", was developed and applied in practical studies.
2. Equipment and materials
Experimental research was performed on a Russian EDM machine 04EP-10MF2 with a short bipolar pulses transistor generator of the nanosecond range. The processing was carried out by tungsten tools electrode with a diameter of 0.25 mm. The workpiece is made up of multiple tightly pressed blades made of stainless steel 65H13 (Russian designation, analogue of AISI 425 Mod) with a total thickness up to 3.8 mm. During processing, as the working fluid was used the tap water.

In this work, the size measurements and shape errors of the obtained holes were measured using the Levenhuk D70L digital microscope, previously calibrated to determine the sizes with the help of the Olympus micrometer object, which is a glass plate with a micrometer scale. In order to process the obtained digital images of microholes, the Levenhuk ToupView software package was used.

3. Results and Discussion
The technological scheme of the developed method is presented in Figure 1, a. The sample in which the micro-hole is machining, presents a pile that consists of many N blades 3, tightly pressed against each other by means of a screw 4, an insert 5 and metal clips 6. The thickness of one blade is about 0.1 mm. The processed sample is fixed in the device 1, adjusted on the table 2 of the EDM machine. After machining holes in the pile of blades with an tool electrode 7, it is disassembled and, successively, starting from the upper blade, the obtained holes are measured using a digital microscope (figure 1, b).

While using this method and workpiece construction, it seems possible to determine the diameter in many N sections of the hole, to establish the nature and regular relationships of changes in the diameter (taper) of the hole, as well as its deviation from circularity (ovality), depending on the depth of the cross-section micro-hole, to find a mathematical model of changes in the hole diameter in depth. The application of this method is especially effective in research of blind micro-holes, as well as non-cylindrical holes, the measurement of which is especially difficult.

Based on the results of research of 10 holes profiles with a diameter of 0.25 mm and a depth of 3.8 mm processed using the developed method, it was concluded that the most significant breakdown and
the greatest ovality are formed in the upper sections of the hole. At the entrance of the hole, the ovality and average taper increase slightly, because as the tool electrode enters the workpiece, it is affected by the resulting force of electric discharges, which can deviate the axis of the non-rigid tool electrode from the feed axis within the backlash value. Even a slight deviation of the tool electrode axis from the feed direction during entry can lead to a significant increase in the breakdown and ovality of the hole.

In connection with this observation, there was carried out an experiment where the dual-mode EDM of hole was used. A small part of the hole (about 10% of the total depth) for stabilizing the process of entering the tool electrode into the workpiece was processed in the “soft” mode with low pulse energy $E_{\text{min}}$, then the main part of the hole was machined in a significantly more “rough” high-performance mode with high pulse energy $E_{\text{norm}}$ (figure 2).

![Figure 2. The micro-hole dual-mode EDM scheme.](image)

Within the experimental research, two groups consisting of four holes were processed. The EDM of the first group was performed in a constant high-performance mode with a pulse energy $E_{\text{norm}} = 0.353$ mJ. The EDM of the second group was carried out using two modes: to a depth of 0.3 mm, the processing was performed in the “soft” mode with low energy $E_{\text{min}} = 0.021$ mJ, then the mode was switched to the $E_{\text{norm}} = 0.353$ mJ, where the rest part of the hole was processed. Processing was carried out at a constant pulse frequency $f = 44$ kHz. To stabilize the processing, the tool electrode was given vibration with a frequency of 380 Hz and an amplitude of 0.01 mm.

![Figure 3. Images of the upper blades: a – a dual-mode EDM with entry in the “soft” mode; b – with standard EDM in high-performance mode.](image)

According to the results of the experiment, the two-mode EDM of the small holes showed a significant decrease in the breakdown (by 17.5%) and taper (by 10.5%) of the holes. Figure 3 shows the images of the holes in the upper blades, that were obtained with the two considered processing
options. It is clear that with a dual-mode EDM there are no surface defects on the input edges of the holes, and that is an important parameter for ensuring the machined holes quality.

4. Conclusion
Based on the research results, a new method for the assessment of the EDM micro-holes accuracy was developed. This method allows estimating to a high precision the errors in size and shape (taper, ovality) of the holes with different cross-section heights and with the axial longitudinal section of the hole. The application of this method is especially effective in research of blind micro-holes, as well as non-cylindrical holes, the measurement of which is especially difficult. The application of this method allows finding a mathematical model for changing the diameter of the hole depending on the cross-section depth.

The developed method was used in an experimental research of the hole profiles, that were obtained by EDM. It was found that at the input of the holes, the ovality and average taper slightly increase. In this regard, an experiment was carried out using dual-mode hole machining with the entering of the tool electrode into the workpiece in the “soft” mode with low pulse energy. According to the results of the experiment, the two-mode EDM of small holes showed a significant decrease in the breakdown and taper of the holes, as well as the absence of surface defects of the input edges of the holes.

Application of the developed method of measurements allowed increasing significantly the efficiency of studying the EDM micro-holes accuracy.

5. Acknowledgments
The article was prepared within development program of the Flagship Regional University on the basis of Belgorod State Technological University named after V.G. Shukhov, using equipment of High Technology Center at BSTU named after V.G. Shukhov.

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