Parametrization and manufacturing of a combined electrode tool using additive technologies and modern computer-aided design systems

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Abstract. The research is aimed at modernizing the technology of designing and manufacturing an electrode instrument for electrical processing methods in order to reduce costs in terms of experimental design and individual production. In this regard, the article is aimed at disclosing the possibilities of using modern computer-aided design tools and rapid prototyping technology for the manufacture of a complex profile tool for individual and experimental production. The materials of the article are of practical value for enterprises of the machine-building complex, as they allow making changes in the technology of designing and manufacturing electrode tools for electrical processing methods and using modern computer-aided design systems and additive technologies that reduce the cost and increase the variability of its application.

1. Introduction

Currently, in all branches of engineering production (aviation, automotive, architecture, medicine, etc.), there are active changes associated with the complication of the shape of the surfaces of various parts, due to a number of reasons, from design features and strength and weight and size characteristics to ergonomics and aesthetics.

In this regard, to obtain such surfaces are actively used modern computer-aided design tools. According to research by scientists Nabil Anwer (France), Seyed Farhad Hosseini (Iran), Behnam Moetakef-Imani (Iran) and Chen Ming (China), such technologies play an important role in the design and production of the product due to the wider use of production and processing technologies in product development process [1-3].

As an example of such surfaces, one can give an example of designing an electrode-tool for electrical processing methods used in a single or pilot production, when tool manufacturing using classical production methods for economic or labor costs is not effective. In such situations, additive technologies are now increasingly being used. As the analysis shows, the use of additive technologies for the manufacture of a solid electrode tool is not new [4].

Additive manufacturing is used as an alternative to traditional processes used to mold tools, thanks to its free-form ability to create complex geometries without compromising the mechanical properties of the tool. In a study by S L Campanelli compares the characteristics of the injection molding process using metal inserts made using both traditional technology and selective laser melting (SLM) [5].

In this connection, the problem of designing, parametrizing and manufacturing complex geometric shapes with a surface continuity of G2 or higher becomes relevant.
2. Materials and methods

In this regard, the issue of calculation, design and implementation of the electrode-tool (ET) that meets the requirements becomes relevant. The method of calculating the geometry of the instrument for the case of electrochemical machining is well described in the literature [6] and is reflected in mass production for the case of a solid instrument made entirely of conducting material. In this case, an important feature of the implementation of such an instrument is its manufacture based on an integrated approach:

- development of a tool design methodology through the use of modern computer-aided design when the working surface of the tool is formed as a back-equidistant surface profile of the workpiece, taking into account the size of the electrode gap and the thickness of the conductive coating based on the parameters of the process
- manufacture of tools from non-conducting materials by rapid prototyping methods with subsequent application of a conductive layer, the thickness of which is guaranteed to ensure the flow of electrical processes and acceptable durability (copper with a thickness of more than 2 mm, depending on the processing mode).

3. Result and discussion

For the design of the combined electrode-tool, manufactured on the basis of additive technologies, a design scheme for the geometry of the combined ET was proposed, shown in Figure 1.

![Figure 1. Design scheme for the design of the combined ET: 1 - the workpiece; 2 - the combined tool; \(L_{det}\) is the characteristic size of the part; \(L_{ET}\) - the characteristic size of the combined ET; \(L_{pl}\) - the characteristic size of the model after 3D printing, but before applying a conductive coating; \(h_{coat}\) - the thickness of the conductive coating on the end; \(h_{coatb}\) - thickness of the conductive coating on the side surface of ET; \(S\) is a well-established end electrode gap; \(S_b\) - side interelectrodes gap with echo cavity.]

As can be seen from the diagram, the characteristic size of the combined ET model, which is necessary for the implementation of 3D printing, can be determined by the expression:

\[
L_{pl} = L_{det} - S - h_{coat}
\]

In expression (1), \(L_{pl}\) is the specified parameter, \(h_{coat}\) – thickness of the conductive coating will be determined based on the electrical processing parameters. The value of the established end gap is determined in accordance with [3]:

\[
S = \frac{\eta \varepsilon \chi U}{\rho \upsilon_u}
\]

where \(\eta\) is the current output, which depends on the material being processed, current density, electrolyte speed, etc. (specific data are given in [6]); \(\varepsilon\) is the electrochemical equivalent of the material being processed; \(\chi\) – conductivity, electrolyte; \(U\) is the operating voltage on the electrodes; \(\rho\) is the density of the part material; \(\upsilon_u\) is the ET feed rate to maintain \(S = \text{const}\). The thickness of the conductive coating \(h_{coat}\) is determined by the underwater electrical power that meets the requirements of [7].
Modern power supplies of electrochemical equipment provide process current density in the range from 0.4 to 1 A/mm². This is enough to implement almost all technological schemes. The value of the constant technological current \( I_m \) in accordance with the recommendations is determined by the expression:

\[
I_m = F_o \frac{U - \Delta U}{S}
\]  

(3)

where \( F_o \) is the area of the treated surface, mm; \( \Delta U \) is the voltage loss in the interelement gap, according to [8], they are \( \sim 5 \) V. Considering that for most materials and processing schemes \( U = 10-18 \) V, expression (3) takes the form:

\[
I_m = F_o \frac{0.7U}{S}
\]  

(4)

Based on what we can express \( h_{coat} \)

\[
I_m(S + h_{coat}) = F_o(S + h_{coat}) \frac{0.7U}{S}
\]

\[
I_m(S + h_{coat}) = \frac{0.7UF_o}{S}(S + h_{coat})
\]

\[
I_mS + I_mh_{coat} = \frac{0.7UF_o}{S}S + \frac{0.7UF_o}{S}h_{coat}
\]

\[
I_mh_{coat} - \frac{0.7UF_o}{S}h_{coat} = \frac{0.7UF_o}{S}S - I_mS
\]

\[
h_{coat}\left( I_m - \frac{0.7UF_o}{S} \right) = S\left( \frac{0.7UF_o}{S} - I_m \right)
\]

\[
h_{coat} = S\frac{(A - I_m)}{(I_m - A)}
\]  

(5)

Summarizing the above expressions, we can conclude that the geometrical dimensions of the combined ET realized using additive printing are a function of the geometrical size of the part corrected by the amount of the established gap and the thickness of the coating, the latter being constants determined by the processing modes:

\[
L_{pl} = f(I_{det}, S, h_{coat})
\]  

(6)

where \( S \) is the const, determined from the law of anodic dissolution [cm]; \( h_{coat} \) – determined by the expression (5).

However, this method is not suitable for electroerosive processing (EEE) due to the wear of the electrode tool during operation.

From the literature [9] it is known that the thickness of the conductive layer, guaranteed to allow the implementation of the electrical parameters of the EEE, should ensure the transmission of the total energy of the pulses involved in the electrical erosion process:

\[
W_u = \frac{\rho}{f}
\]  

(7)

where \( f \) is the pulse frequency, Hz; \( \rho \) is the power of the pulses, determined by the expression:

\[
\rho = U_{av}I_{av}
\]  

(8)

where \( U_{av} \) – voltage in the interelectrode gap, which is in the range of 0.5÷0.75 \( U_{xx} \) (no-load voltage); \( I_{av} \) – current on the electrodes, which is in the range of 0.5÷0.75 \( I_{sz} \) (short circuit current).

In this regard, the thickness of the coating required to ensure the flow of electrical processes in the OEP, can be determined by the formula:

\[
h_{coat} = \frac{2\rho}{W_u}L_{ET}
\]  

(9)
where \( \rho \) is the specific resistance, \( L_{3d} \) is the length of the electrode tool.

In turn, \( h_{coat} \), the amount of coverage that will be removed due to electrical erosion, according to the literature [3], can be determined by the formula:

\[
h_{coat} = t_u^{0.15} \left( k_3 + k_4 \ln I_w + k_5 \ln t_u \right)
\]

(10)

where \( k_3 \) – coefficient characterizing the destruction of the electrode material of the workpiece per unit of input energy; \( k_4 \) is an empirical coefficient characterizing the degree of influence of current strength on wear of ET; \( k_5 \) is an empirical coefficient characterizing the degree of influence of impulse time on the wear of ET.

The proposed results were tested and confirmed under experimental conditions. The efficiency of the tool has been tested [10]. This suggests that this method can be used to parameterize and manufacture complex combined tools for single or small-scale production using additive technologies.

The proposed methods for calculating the parameters of the working surface of ET for electrical processing methods were implemented in the form of the software “Electrode-tool parameterization subsystem for EDM processing” software. This software was written in VB.NET in the illogic software module, which is a convenient and flexible way to control parameters when designing parts in the Autodesk Inventor computer-aided design system. Based on the developed software, an ET for processing EDM was developed and implemented (Figure 2).

**Figure 2.** Stages of design and implementation of a complex profile, combined El.

The results were confirmed under experimental conditions:

- calculation of the working surface of the EI;
- designed ET using the developed software;
- performance tests of the combined ET for EEE were performed, which showed its good durability.

To do this, the hard-to-reach areas of the impeller of the turbopump assembly, produced with a current of 4A, a duty cycle of 2, a frequency of 440 kHz, and a treatment area of 100 mm², were processed. During the experiment, the ET resistance was more than 30 min, and the roughness of the treated surface corresponded to the value \( R_a = 1.25-0.63 \) \( \mu m \) [8].

4. Conclusion
The results obtained are of interest for various branches of engineering production, in which there are parts finishing or pilot production using electrical methods, processing, when the manufacture of an electrode-tool by traditional methods causes some difficulties. The proposed technology for the design and manufacture of electrode-tools for electrical processing methods significantly expands the area of their technological use by reducing the cost and increasing the variability of their application. The technology of electrode tool parameterization can be supplemented and incorporated depending on the shape and characteristics of the process.

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