Ceramic coatings synthesis on valve metals and alloys by micro-arc oxidation

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Abstract. The most pressing tasks in engineering and materials science are the synthesis of high-quality coatings with high durability and corrosion resistance. This paper presents ceramic coatings synthesis on valve metals and alloys by micro-arc oxidation. The approach is based on advanced morphological approach. The approach is to generate a sequence of algorithms, comparison and selection of the set of rational variants of technological solutions. The approach allow to reduce the dimensions of the morphological set and improve the efficiency of search procedures.

1. Introduction
The most pressing tasks in engineering and materials science are the synthesis of high-quality coatings with high durability and corrosion resistance. The search is under way for new technologies to provide multifunctional coatings. Micro-arc (plasma) oxidation (MAO) consists in the formation of a part on the surface under the influence of micro-arc discharges of high-strength wear-resistant coating, consisting mainly of Al₂O₃ (corund) and other aluminium oxides. The complexity of the flowing physical and chemical processes leads to consideration of various options for the implementation of MAO-coating [1-4].

The investigated set of technological processes is relatively new and rapidly developing. Therefore, the potential number of technology variants is large. As a consequence, morphological approaches can be used for classification and synthesis of technologies.

2. Morphological approach
For the stage of structural analysis and synthesis of innovative engineering and technological systems (TS) the intuitive and discursive methods can be used [5, 6]. The most common method among the discursive techniques is morphological analysis with building of morphological matrix (MM) (figure 1). By frequency of use, morphological methods are the first among ranks of discursive approaches. Thus, according to statistics compiled in 2009 by German scientists, the total number of firms using the morphology is more than 40%, while regularly use it more than 20% [7]. Morphological synthesis is regarded as a methodology to streamline the problem to be solved. At present, there are many methods to search and synthesize solutions based on the morphological analysis in in a variety of physical and engineering areas [8, 9]. One solution of this problem, in our view, consists in using models of the clustering and set theory. In this respect, it seems appropriate to
resort to advanced morphological approach (AMA) with following physical-mathematical modeling and experiments [10, 11].

![Morphological matrix](image)

**Figure 1.** Morphological matrix.

3. **Micro-arc oxidation technology synthesis**

The main design and technological parameters influencing the synthesis of MAO coatings include the used modes of coating formation

- by changing electrical parameters - potentiometric or galvanostatic;
- on the polarity of the applied voltage (anode, cathode, anode-cathode, cycling regimes of different polarity with pauses);
- ratios of cathode and anode modes, as well as pauses between them;
- used electrolytes by number of components and chemical nature - silicate-alkaline, sour, etc.;
- on frequency control of processes and possible elemental base of process management;
- by the way of forming a discharge (soft, soft-hard, hard-soft, hard) etc.

The main features that provide the process of MAO include the main modes of coating formation, divided by [1-3]:

1. Energy parameters:
   - changes in electrical values (potentiometric or galvanostatic);
   - the polarity of the applied voltage (anode, cathode, anode-cathode, cycling modes of different polarity with pauses between them);
   - the way of forming a discharge (soft, soft-hard, hard-soft, hard) etc.
2. Used electrolytes:
   - using a number of components;
   - chemical nature (silicate-alkaline, acidic, etc.);
3. Control of application processes:
   - frequency process control and possible elemental base;
   - process control.
4. Material for application - vent metals and alloys, graphite, etc.

To assess the options with the help of expert assessments, MM was drawn up with the following features - coating modes, electrolytes used, materials used, application control, frequency regulation, etc. Any set of elements of all traits (one of each line of the morphological table) is a possible version of the technology. The power of the morphological set is 20736 variants [3].

Twelve TS reference variants, formed from patent descriptions and well-known solutions, were also included in MM. In the future, a number of criteria were chosen, characterizing the constructive
and economic indicators of TS and expertly assigned weights on the basis of the method of attributing points, which has an advantage in choosing the freedom of action over the methods of ranking.

During synthesys 1,648 variants were generated and 256 selected for further clustering. Of the 256 generated and selected variants, 9 clusters were formed (figures 2, 3). Among all clusters, cluster 9 has the highest rating (by 14% than the average estimate), which was primarily investigated.

![Figure 2. Morphological solutions space.](image2)

![Figure 3. Clusters comparison.](image3)

A specific feature of the reference variants and most variants of this cluster is the control of flowing processes with the help of bipolar transistors with an insulated gate bipolar gate transistor (IGBT), which leads to an increase in the ability to control and control. These variants differ from other variants - inventions of higher characteristics [12].

As a result, TS was created, which is a combination of variants 8-10 and extended in the sign of the used electrolytes. TS is characterized by a wide range of process control capabilities, in particular, at the initial stage only anode mode is implemented, which allows to quickly increase the ceramic coating, in the future anode-cathode mode of application with frequency control with the help of IGBT controlled by the microcontroller. The transistor involves anode and cathode voltage on the parts when they reach the level of voltage they need for the process and trims the pulses of the current at the time of the termination of the process. The latency time between cathode and anode cycles is also set. For example, the cathode pulse that prepares the work of the anode should lie within 0.5...1. Compliance with these conditions allows you to optimize the process coverage. In addition, the process is soft, the full use of the useful part of the current pulses, and thus the minimum electricity consumption and high quality of coverage.

The device allows to control technological processes within wide limits (figure 4). Technological process is realized in the following way. Detail 5 is placed in the electrolyte and connected to the anode of power unit 2. Transistor includes anode and cathode voltage on the parts at the moment when it reaches necessary for the process level and cuts off current pulses at the moment of process termination at duration of pulses \( t_A \) and \( t_K \) (figure 5). The delay time between cathode and anode cycles \( t_{AK} \) is also set. The fulfillment of these conditions allows optimizing the process of coverage. In addition, a soft start of the process, full use of the useful part of current pulses and thus a minimum power consumption and high quality of the coating are provided.
Figure 4. Principal scheme of MAO installation with automated coating control process.

Figure 5. Processing process control (A - anode, K - cathode, IA, IK - anode and cathode electric current, tAK, tKA - temporary delays between the onset of anode and cathode cycles).

The proposed TS makes it possible to fully regulate the application process, so the improvement in the quality of coating is achieved, for example, by the fact that at the beginning of the coating the process is completely in anode mode.

A pilot installation of MAO with extensive process control capabilities has been created for the chosen TS. The installation obtained hard-to-wear ceramic coatings on valve metals and alloys (figures 6-8).
4. Conclusion
The proposed approach gives specification and order of structurization of the problem being solved. The degree of substantiation of the decisions made increases. Having analyzed a lot of decisions, it is possible to narrow down the amount of information for making a final decision by a specialist.

For the process of micro-arc oxidation, an experimental setup has been created and the following characteristics have been achieved:

- the possibility of coating on complex products, internal surfaces and hidden cavities;
- obtaining coatings of thickness from 0.05-0.2 mm to 0.3-0.8 mm with adhesion comparable to the strength of the substrate material;
- possibility of full automation of the process of micro-arc oxidation itself;
- wide possibilities of process speed regulation (by current, voltage, frequency characteristics and ratio of anode and cathode components).

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