Power Supplies for Microarc Oxidation Devices

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Abstract. The issues of the microarc oxidation technology have been considered, the review and classification of the electrical modes of the microarc oxidation have been carried out. The analysis of the known circuit solutions to build the process power supplies for microarc oxidation has been conducted; its strengths and weaknesses have been defined. The review of the known industrial designs of the power supplies for microarc oxidation has been carried out. The requirements for process power supplies have been defined, it's structural and circuit implementation options which ensure gaining coatings with a wide complex of set physical and chemical properties have been suggested. The mathematical models which allow evaluating the electronic power device operating modes, have been developed for the proposed power supplies implementation options.

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Introduction

The development of new eco-friendly technologies of applying high-efficiency and reliable coatings to protect and harden metal products is now one of the most crucial tasks for the modern science and engineering. It is caused by the aggressiveness of the applied process environments and the product operating severity which results in stepping up the requirements for construction materials. One of the new and promising types of mainly metallic material surface treatment and hardening is microarc oxidation (MAO). The MAO method allows obtaining multifunctional ceramic-like, wear-resistant, corrosion-resistant, heat-resistant, electrical insulating and decorative coatings with a unique set of physical and chemical properties for applying in various fields of engineering. The physical and chemical properties of the coatings gained by microarc oxidation are significantly better than the properties of the coatings formed through the classical anodizing, oxidation, etc.

The implementation of the microarc oxidation method is to immerse a sample part in the plating bath filled with electrolyte and to feed polarization voltage to its terminals. As a result at the metal-oxide-electrolyte interface the microarc discharges occur, followed by high local temperatures and pressures.

The surface microdischarges have a very substantial and specific impact on the coating formed as a result of which the composition and structure of the resulting oxide layers are substantially different, while its properties are significantly better than ones of the normal anodic coating films. The other positive features of the microarc oxidation process are its eco-friendliness, as well as the absence of the need for careful surface preparation at the beginning of the process flow and the use of refrigeration equipment to produce relatively thick coatings.

Body. The standard unit for the MAO process (Fig. 1) consists of the plating bath and the process power supply. The equipment configuration of a particular unit is determined by the specific operating modes and performance parameters, such as the purpose of the formed coating, the maximum dimensions of work pieces, performance, cost, etc. The unit could be optionally equipped with the electrolyte cooling and agitation systems.

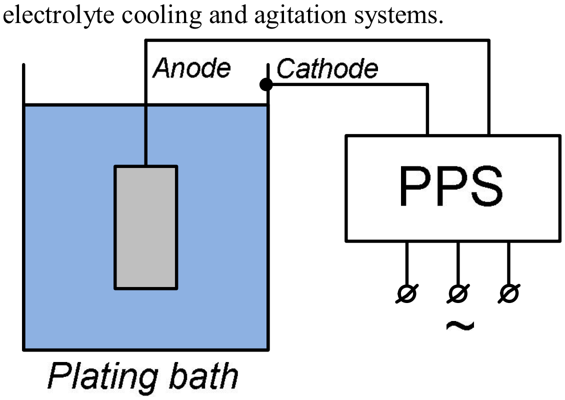

Fig. 1 – Unit Block Diagram for the Microarc Oxidation.

Nowadays the microarc oxidation technology is in its infancy. The works on both studying the theoretical issues of this phenomenon, and improving the technological methods and tools to increase its efficiency and to extend the range of the work alloys are carried out: testing of new electrolytes, selection of optimum modes, as well as the creation of new process power supplies, which allow its implementation.

In the context of the process control in these units the following objects could be drawn up: The process power supply to operate an electric mode, the electrolyte priming system for the electrolyte cooling and agitation, the electrolyte cooling system, the ventilation system for removing gases evolved. The structure, composition and physical and chemical properties of the formed coatings are directly dependant on the composition of the electrolyte, the workpiece material, the polarization mode, the electrolyte density and temperature. The electrolyte composition and the alloy of the work material are determined at the initial stage of the MAO preparation, the management of the materials surface treatment modes is carried out by varying the polarization voltage generated by the process power supply. Thus, the main factor which determines the properties of the formed coatings is the polarization mode which is determined by the electrical mode of the process power supply (PPS).

The survey of various literature sources (publications, patents, etc.) showed the presence of a large number of different electrical PPS modes used upon the surface treatment through the microarc method to gain the coatings with a certain set of physical and chemical properties. These works typically contain the information on the composition of the electrolyte and the polarization mode. In some cases, the power supply circuitry for the implementation of any given microarc oxidation method is carried out [1-6].

The conducted PPS analysis allowed classifying the applied electrical modes of MAO coating forming (Fig. 2).

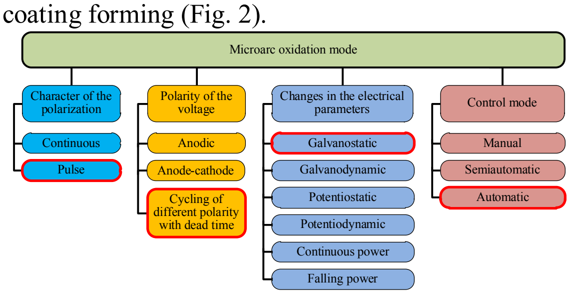

Fig. 1 – Classification of the Microarc Oxidation Modes

Most PPS which implement these modes are based on the capacitor circuits, allow outputing the PPS current pulses with the supply frequency. In some PPS circuits the methods of voltage doubling are used. However, a common drawback of these circuits is the low load capacity. In the controlled PPS the controlled thyristor rectifier is used to implement the unipolar mode, and for bipolar mode - reversible thyristor rectifier is used. The thyristor rectifiers allow regulating the output current intensity by varying the thyristor firing angle, which enables to automatically maintain the required MAO mode due to the use of the appropriate management system. However, the proposed PPS options have a limited output variables regulating range (output current, voltage, pulse duration, etc.), which extremely narrows the range of the possible properties of the formed coatings.

The review of the known PPS industrial designs [7-9] showed the availability of several manufacturers of the equipment to provide the MAO process in the market. However, most of these PPS specifications allow realization of only a limited range of the electric modes for the MAO coating formation. In addition, a significant drawback industrial PPS is the fixed frequency of the output voltage pulses that is equal to 50 Hz upon single-phase supply and 300 Hz power upon tree-phase one.

Improving the coatings quality and gaining its new physical and chemical properties could be carried out in two ways: by developing and use of new electrolyte compositions or aplying special electric modes of the coating formation. Currently, a large number of studies on coating properties due to the electrolyte composition, which is typically unique for each material and mode have been conducted. The more promising trend in the context of the qualitative improvement of the coating properties is the extension of the PPS functionality, as confirmed by a large number of the recently published results of the experimental studies on the dependence of the physical and chemical coating properties on the PPS electric mode. Currently, in the field of the microarc oxidation technology there is a trend in using the pulse mode when processing.

One of the most promising trends in the MAO method development is now the development of the current regulators, which provide a wide range of the MAO electric modes, allow forming coatings with a given set of physical and chemical properties. Such MAO modes require the creation of new types of the current regulators based on the application of the modern element base of the power electronics and microprocessor technology, which possess intellectual properties. One of the ways to gain the coatings with the set properties is to constantly establish the database of the coating properties, which include the mode sets of the carried out MAO processes upon the appropriate electrolyte composition. The generalized block diagram of the power supply for the microarc oxidation device, which ensures gaining the coatings with the set properties are represented on the Fig. 3. The coating parameters are inserted using the data input device. Then, the inserted parameters are mapped to the coating database elements and the process parameters which are transmitted as the set parameters to the controller of the automatic power supply management system are formed. The power module generates the output voltage pulses (output current pulses). Measuring instantaneous values of the process parameters are carried out by sensors: current, voltage and electrolyte temperature. The measured values are used to provide feedback to the automatic control system. The integrated load parameters determination module carries out the indirect determination of the coating parameters on the basis of the parameters of the transient process of the load current change.

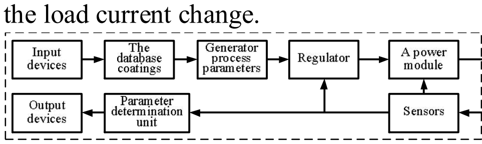

Fig. 3. Block Diagram of the Intellectual Power Supply for the Microarc Oxidation Device

The microarc oxidation process feature is the non-linear nature of the load, the parameters of which vary during the process time. This feature produces certain difficulties in the development of the process power supplies. For the purposes of research and analysis of transient processes which occur during the operation of the power supply with the MAO-load, it is convenient to use the equivalent substitution circuit shown in Fig. 4.

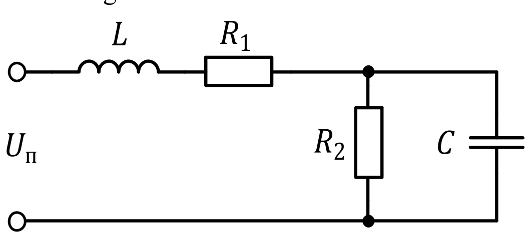

Fig.4. Equivalent Circuit of the Current Regulator Load Substitution.

It has been established that the coating properties are directly dependent on the microarc system parameters, namely on the values of the active and capacitive components [10]. Thus, determining the load parameters (the values of the capacity and resistances shown on the Fig. 4) allows implementing the another way to gain the coatings with the set properties, which is to permanently monitor the load parameters by analysing the parameters of the transient process of the load current change which results from feeding the rectangular voltage pulse to the load.

According to the requirements imposed to the power supplies for microarc oxidation, which ensure gaining the coatings with the required properties, two options for its implementation are suggested. The first one is based on the controlled thyristor tree-phase reverse rectifier bridge (Fig. 5).

The power module of the thyristor regulator is the controlled reverse rectifier bridge. The peculiarity of the proposed current regulator which is distinguished from the known equivalents is the use as the control device of the microprocessor control unit - MPCU which regulates the output current by the method of the pulse and phase control of the thyristor module. This regulator ensures bipolar pulses of sinusoidal voltage with a given mean value of the output current. Minimum pulse duration is 3.3 ms, which is due to the natural commutation of the power module thyristors. Regulation of the load current is carried by a pulse-phase control thyristor module. For the feedback (as for the process status) the load current sensor - LCS and the electrolyte temperature sensor - ETS are applied. The line voltage sensor (LVS) provides synchronization of feeding the control pulses with the moments of crossing zero the line supply voltage.

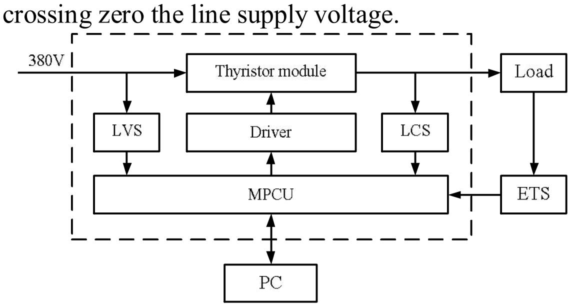

Fig. 5. Thyristor PPS Block Diagram

For the purpose of investigating the MAO device modes, analysing the transient processes in the power devices (thyristors) and optimizing the parameters of the proposed current regulator management and setting system its model in the LTspice software package has been developed (Fig. 6).

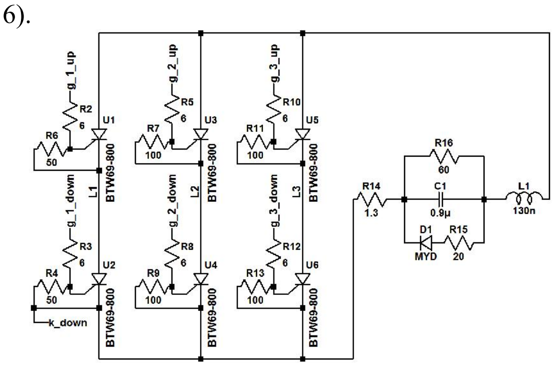

Fig. 6. Model of the Power Module of the Thyristor Current Regulator

Modelling the thyristor controller allows evaluating the capacitive component of the load current, which significantly affects when using high-frequency thyristors. When using the low-frequency thyristors the capacitive load current occurs when switching, and the thyristor is in the active operational mode, which results in the absorption of the capacitive current component. Thus, when using a low-frequency thyristors the load could be considered as an active one that allows using the standard power module design methods. Using high-speed thyristors results in the need for accounting the high-accurate transient processes which should be taken into account in the design procedure (Fig. 7).

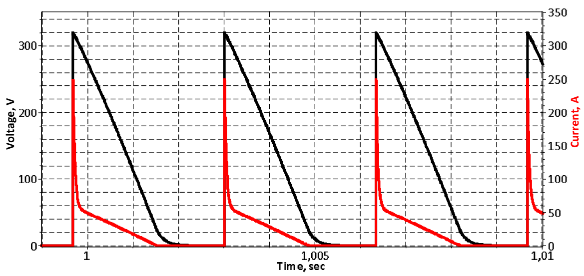

Fig. 7. Modelling the Output Voltage and Load Current when the Thyristor PPS Operation on the High-Frequency Thyristors

When modelling the required parameters of the load-bearing components have been evaluated, its heat operating mode has been studied, which is reflected in the developed methods of the thyristor current regulator design calculations subject to the load type.

The MPCU module implements the single-circuit system of load current stabilization according to the proportional control action:

$$\varphi(t) = \varphi(t-1) + K_c \cdot \varepsilon(t);$$

The developed model also allows checking the calculated coefficient values of the used control system regulator.

The MPCU algorithm also implements the required set of the service functions: limiting the output voltage amplitude, starting anode current, calculation of the electrolyte resource by counting the charge quantity, the electrolyte protection from overheating, etc. The set current regulator module is PC connected to the MPCU through the noise-protected communication channel. The developed specialized software allows setting the processing modes, controlling and monitoring the parameters, as well as logging the whole MAO process (Fig. 8).

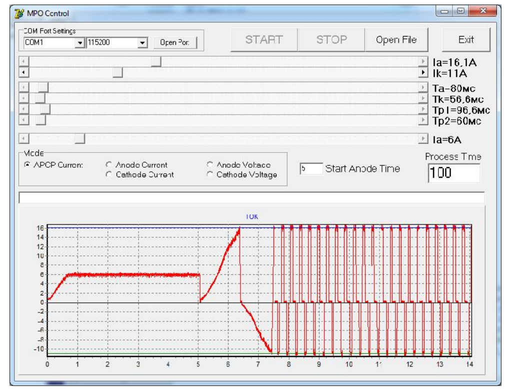

Fig. 8. Interface of the Current Regulator Control Program for MAO

A second version of the current regulator for MAO is the transistor inverter current regulator [11], the structure of which is represented on the Fig. 9.

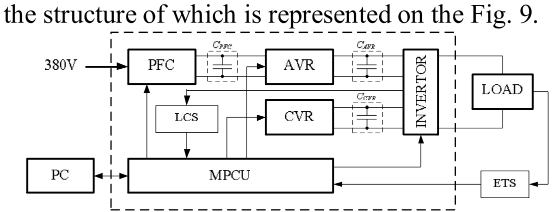

Fig. 9. Unit Block Diagram for MAO with Transistor Current Regulator

In the proposed current regulator the bipolar voltage pulses of the given duration are generated by the voltage transistor inverter (Fig. 10).

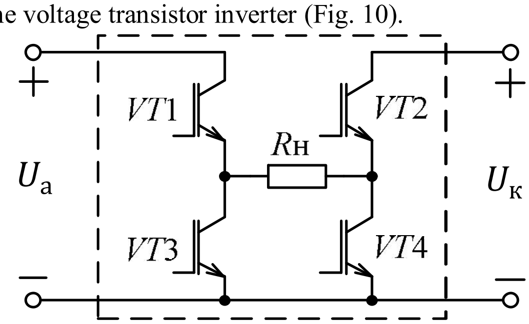

Fig. 10. Conceptual Voltage Inverter Diagram

Anode voltage pulse is generated by opening the *VT1* and *VT4 transistors*, the cathode - by *VT2* and *VT3* ones, during the dead times all transistors are closed (Fig. 12). For the purpose of plotting the voltage pulse amplitude separately the independent anode and cathode voltage regulators are used (AVR and CVR) (Fig. 1), which are the pulse downconverters. Thus, the PPS output pulse amplitude is defined by the AVR and CVR output voltage levels (*U*a and *U*c). The voltage regulator supply is carried out from the output capacitor of the power factor corrector. (PFC) *C*PFC. The PFC use is due to the high degree of the non-linear distortion of the AVR and CVR pulse converters. It should be noted that the PFC use is also due to the need for increasing the output regulator voltage to the value of 900V. The control of the voltage inverter, the voltage regulators and PFC operation is also provided by the microprocessor control unit. The MPCU operational algorithm for the transistor current regulator as in thyristor regulator implements the single-circuit system of the mean current value stabilization during the pulse time (Fig. 9) by regulating the voltage pulse amplitude. The correction of the process parameters is carried out in every voltage pulse repetition period. MPCU of the transistor regulator implements the same service functions that are used in the thyristor regulator.

It should be noted that in the transistor current regulator one of the most promising MAO mode - the anode and bit one could be implemented [1]. Its peculiarity lies in the fact that after feeding the anode voltage pulse after a certain period of time load bypassing (the terminal plating bath) is carried out, which results in the discharge of its capacity. For this purpose the *VT3* transistor triggering is quite enough (*VT3 circuit – VT4 diod*e, Fig. 10).

For the purpose of investigating the supply modes the mathematical model of the transistor current regulator developed in the LTspice software package has been used (Fig. 11). The model allowed analysing the transient processes in the load-bearing components, evaluating the impact of the load type on its load operation modes (maximum current values, heat operating modes, overload, etc.), determining the parameters of the control system which are necessary to regulate the output current. The results of modelling the inverter PPS operation (Fig. 12) also showed the need for accounting the capacitive current component at the stage of the design calculations of the inverter load-bearing components and pulse voltage regulator.

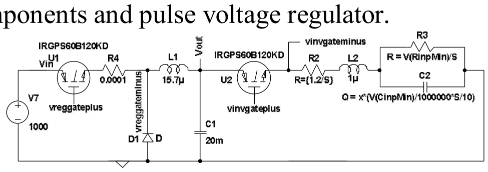

Fig. 11. Integrated Model of the Transistor Current Regulator for the MAO Devices

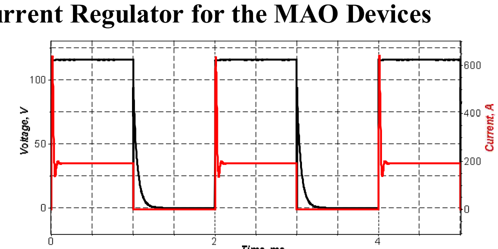

Fig. 12 Modelling the Output Voltage and Load Current during the Inverter PPS Operation.

Conclusions.

Two versions of experimental samples of the current regulators have been produced based on the investigations made, which are tested in the laboratories of the Chemical Engineering at the South Russian State Technical University (Novocherkassk Polytechnic Institute). The devices ensure gaining the composite coatings of high functional properties (the coating corrosion resistance is 10-15 times higher compared with the equivalents, the parameters of the resistance to wear and the kinetic friction coefficient are higher in several times, etc.) [12-14]. The conducted studies on the properties of the MAO coatings allowed developing the technology of gaining the optically black coatings [15-16], which are widely used in the energy-saving technologies and the professional equipment. The works on updating the database of the coating parameter dependencies on the MAO electrical modes which will allow forming the coatings with the required properties. The test results confirm the maximum regulator effectiveness on the basis of the transistor inverter, which provides a wide range of modes and functions.

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