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CONTRIBUTIONS REGARDING THE IMPROVEMENT OF INSTALLATIONS FOR THE MACHINING OF CONDUCTIVE MATERIALS THROUGH IMPULSE ELECTRIC DISCHARGES IN SUBEXCITATION REGIME

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Abstract. *The method of machining by impulse electric discharges in subexcitation regime (IEDSR) presents a machining method that allows obtaining some superficial layers whose properties differ from the properties of the basic material of the piece. This machining method has a lot of advantages compared to other machining methods such as, formation of the intermediate layer between the deposited layer and the base material, the lack of formation of micro cracks on the processed surface, possibility of using a wide variety of materials and so on. At the same time, the low productivity of the process, obtaining a surface with a high roughness, obtaining a non-homogeneous surface, make inefficient the using the given process. The paper below presents a description of the solution for layer deposition by IEDSR. The endowment of installation with a multi-electrode system that is powered by the generator of impulses and the use of two stepper motors that can execute up to 1800 micro-steps, controlled by a programmable microcontroller, successfully eliminates the disadvantages of the IEDSR machining process.*

Keywords*: Impulse electric discharge, subexcitation regime, multi-electrode system, microcontroller, stepper motors.*

UDC: 620

1. Introduction

The paper refers to the installation for the deposition of superficial layers by impulse electric discharges in subexcitation regime (IEDSR) which consists of two subassemblies:

The mechanical component of the installation is similar to a miniature of a lathe of splinter of a metals, at which can be installed a cutting tool or **multi-electrode system** with n electrodes can be installed, which are powered from the pulse generator. The mechanical component operates on the basis of two stepper motors that can execute 1800 micro-steps per rotation and a motor with collector (10 000 min $^{-1}$) for finishing the surface before machining with IEDSR. The installation is managed by a programmable controller that controls the realization of electric discharge, rotation of the piece and the longitudinal movement of the electrodes.

The impulse generator represents a prototype of the "Razread-M" installation, provided for the mechanical installation with the "multi-electrode" system (4 electrodes).

General objectives: conception, design and realization of the mechanical component of the programmable installation with a multi-electrode system for the deposition of superficial layers with the application of IEDSR.

Specific objectives:

- Increasing productivity in the process of depositing the material on the cathode (processed piece).
- Obtaining a relatively homogeneous layer on the surface of the piece.
- Application of electric discharges (craters with expelled material) with a preset resolution.

Advantages of the installation:

- Increased productivity of layer deposition compared to installations with one electrode;
- Obtaining a layer of deposits (metal, semiconductor, dielectric) through IEDSR in the form of a matrix;
- Obtaining a wide spectrum of thicknesses of the deposited layer;

- Possibility of finishing machining until machining with IEDSR;
- Accessibility of microcontroller programming (C ++).

2. Installations of machining with impulse electrical discharge

There is a wide variety of installations for the purpose of superficial machining of materials with the application of impulse electric discharges. There are known a series of installations produced by the Experimental Factory of the Institute of Applied Physics of the Academy of Sciences of the Republic of Moldova type "Elitron" - installations in which the tool - electrode is installed on a lever intended for manual processing, operating in "contact breaking" regime, performed by a vibrator installed on the respective lever. The installation has a low productivity, and the quality of the deposited layer, likewise, is low, which also depends on the skills of the operator. Figure 1, a.

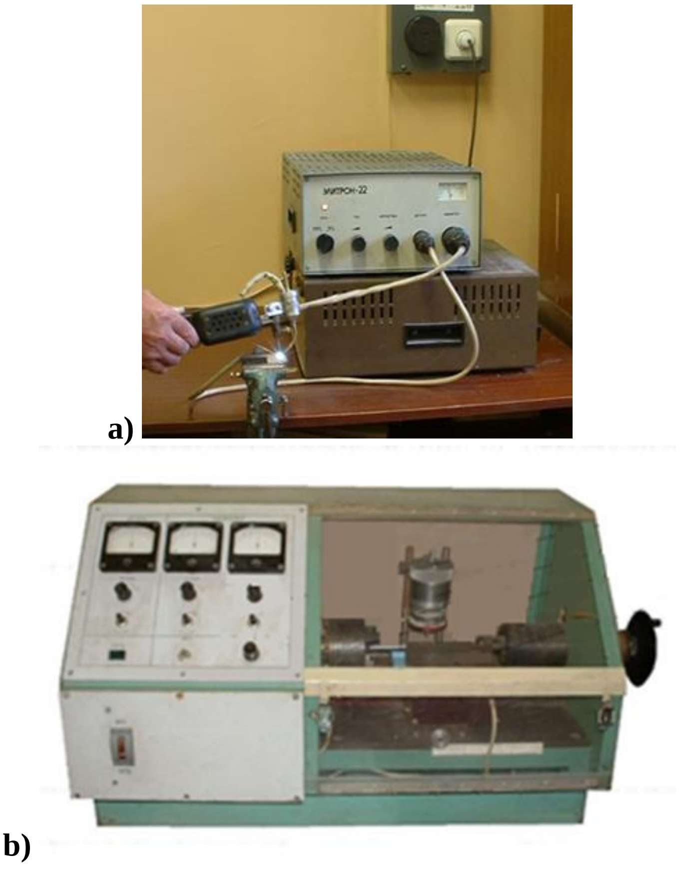


Figure 1.

a). Installation of machining with impulse electrical discharge with "contact breaking";

b). Installation of machining with impulse electrical discharge by applying impulse electric discharges in subexcitation regime.

For the superficial machining of materials with the application of impulse electric discharges in subexcitation regime with or without the application of metal powders in the interstitium (between the electrodes), are known the "Razread" type installations which represent a metal lathe of splintering whose splintering tool is replaced by a powered electrode by a pulse generator that is managed by a command block that synchronizes high voltage electrical discharges and low voltage electrical discharges. This type of installations works in a small number of work regimes. The electric discharges take place ally while the piece is rotated continuously, which leads to an uneven layer of deposits. The piece meets only the resistance of the environment (air) but is rotated with a relatively high power motor that leads to unjustified energy consumption. The capacitor batteries in which the discharge energy is stored serve only for some working energy regimes. The productivity of the mentioned installations is low, likewise the surface quality. All these disadvantages speak of the need to develop installations with the use of new, advanced technologies, and their operation to be controlled by a computer system.

3. Proposed solutions in the improvement of the machining installations by impulse electric discharges

In order to achieve the objectives proposed in the paper, the installation for the processing of conductive materials by impulse electric discharges in subexcitation regime with n electrodes are presented, which eliminates the disadvantages mentioned above.

The advantages obtained from the use of this installation consist in the execution of electric discharges with a high resolution ensured by the rotation of the piece and the longitudinal movement of a multi-electrode system by means of stepper motors, capable of executing 1800 micro-steps per rotation, obtaining a structured surface with a lower roughness comparing to the results obtained at the installations described above.

The operating process of the proposed installation is controlled by a programmable microcontroller, so that it is possible to obtain deposits with a predetermined resolution or to obtain several layers of deposits. Endowing the installation with a multi-electrode system with n electrodes allows to obtain a relatively high productivity of the installation. The energy consumption of the motors used at the proposed installation is ten times lower than the energy consumption of the motors of the installations described above. The installation is presented in Figure 2.

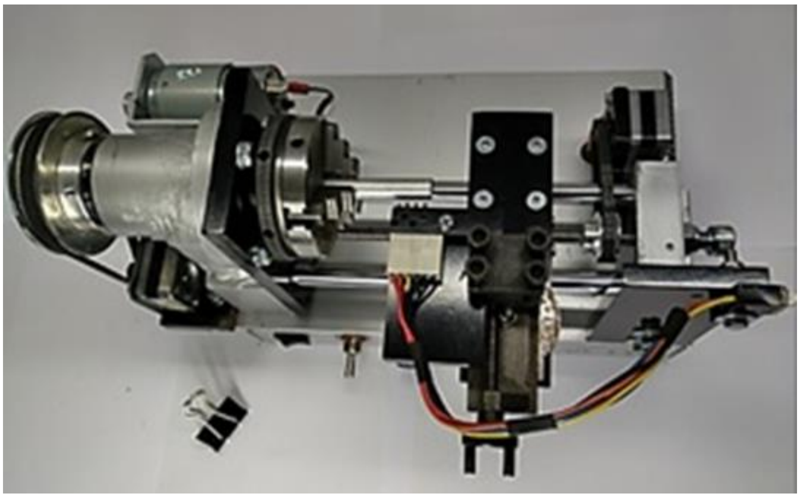
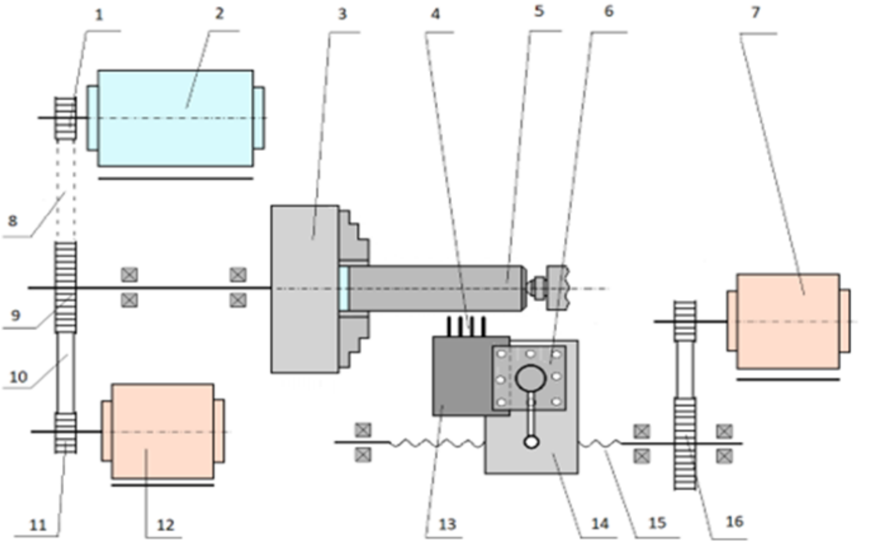


Figure 2. Overview of the mechanical component of the machining installation with impulse electric discharges, in subexcitation regime with more electrodes.

The mechanical component is a miniature of a metal lathe of splinter, endowed with a continuous speed motor (2) and two stepper motors (7, 12), (Figure. 3).

The motor (3) is connected by changing the synchronous transmission belt (10) to position (8), for surface finishing work. The stepper motors (7, 12) are intended to rotate the piece (5), fixed in the mandrel (3), with a very low angular speed and the longitudinal movement of the trolley (14), with micrometric steps. On the tool holder (6), can be mounted a splinter tool for finishing the surface undergone to machining or a multi-electrode system (13) with n positively polarized electrodes for machining the surface by IEDSR. The use of the microcontroller allows the programming of the machining process in such a way as to execute electric discharges on the machined surface with a high resolution, obtaining a uniform surface and respectively a higher quality of the deposited layer, compared to existing installations. Due to the rotation of the piece and the longitudinal movement of the multi-electrode system with micro - steps, the number of electric discharges per unit area can be programmed in a very large range, obtaining different resolutions of IEDSR and layers of different thicknesses, respectively.



1. Belt drive wheel 1;
2. Continuous speed motor;
3. Universal chuck;
4. Electrodes (anode);
5. Workpiece (cathode);
6. Tool holder support;
7. Bipolar stepper motor 1;
8. Synchronous transmission belt;
9. Drive belt wheel;
10. Synchronous transmission belt;
11. Belt drive wheel 2;
12. Bipolar stepper motor 2;
13. Multielectrode system;
14. The trolley;
15. The leading screw of the trolley;
16. Longitudinal transmission of the trolley.

Figure 3. The main mechanical scheme of the machining installation with impulse electric discharges in subexcitation regime with several electrode electrodes

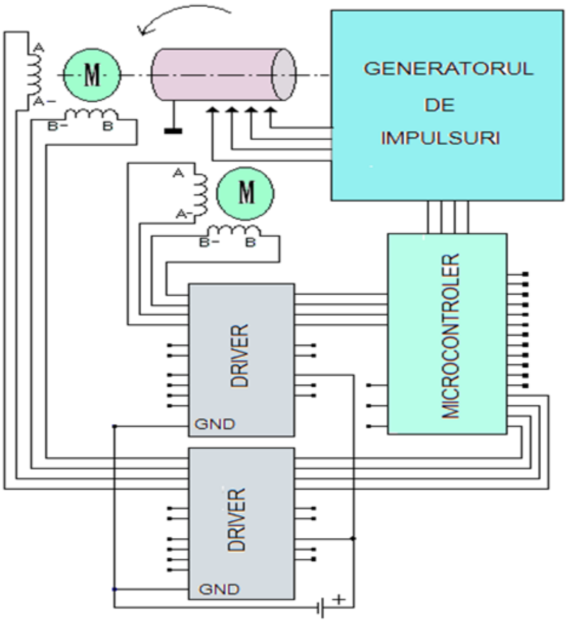


Figure 4. The main electrical scheme of the installation.

4. Electric discharge channel module

The way designed to ensure the smooth running of the process through IEDSR has two distinct components (figure 5). The first component is to create an electrical discharge with an enough high voltage to change the electrical conductivity of the air. For this, it is necessary that on the electrodes there is a potential difference of about 12-20kV. This potential can be obtained by a command applied to the lifting transformer, Tr1. Because this discharge must be synchronized with the circular motion of the sample on which the deposit is to be made, is used a microcontroller which coordinates both, the movement of the stepper motors and the time at which the discharge takes place. The microcontroller used is an ATMEGA328, now produced by Microchip (previously produced by Atmel). This 8-bit microcontroller is endowed with a 32kb flash memory, a 1024bit EEPROM memory and a 2kB memory. It can operate with a tact speed provided by a 16MHz quartz crystal, which ensures extremely good accuracy and time stability for the IEDSR process. Also, this microcontroller can perform complex instructions in a single clock tact which can cover 1MIPS per MHz, under conditions of a ratio of power consumption / optimum processing speed.

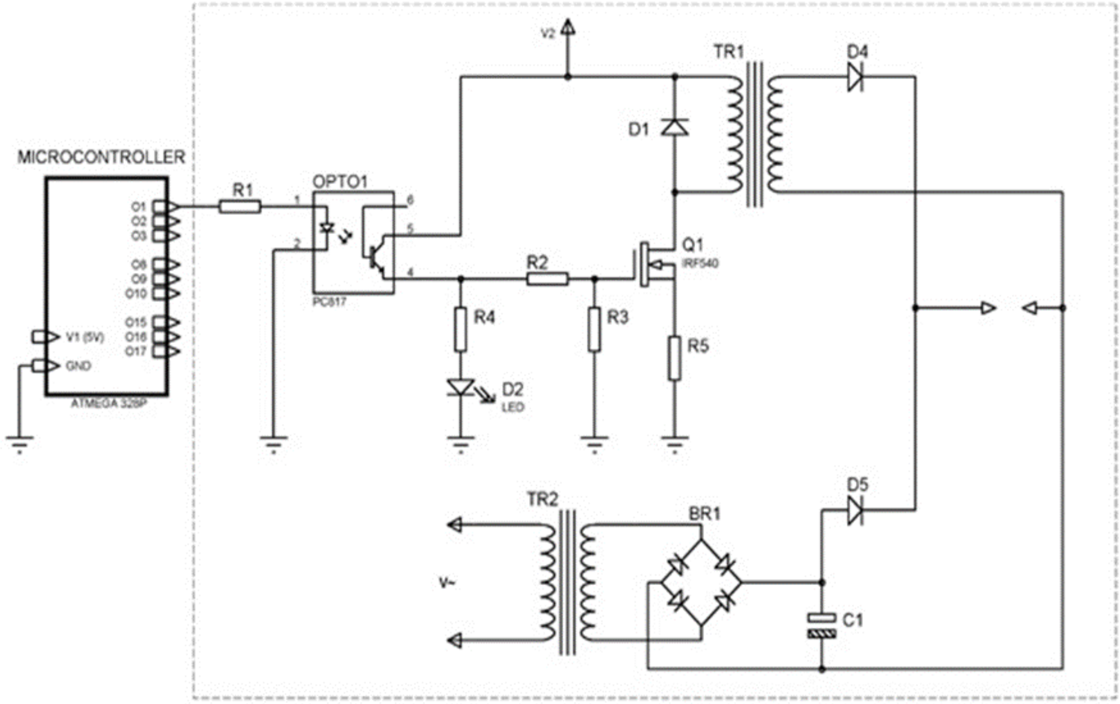


Figure 5. Electric discharge channel module

Also, the ATMEGA 328 microcontroller ensures a number of 23 input/output lines, covering the line requirement for the application named above. Practically, for each pair of electrodes (we consider the anode-piece assembly on which the deposit is to be made) a discharge command output pin is used and as such a demonstration purpose 4 such pairs were chosen. Also, for the command of the stepper motor rotating the trial, 2 pins were allocated for each pole of the motor. The command of motor was further realized in two variants: either by means of a network of power transistors (ULN2003) for each pole or by using a dedicated driver A4988 with the mention that the latter receives commands such as direction of rotation, type of step used and activation and also has current limitation, for the unwanted situation of accidental locking of the motor shaft controlled.

Also related to the microcontroller, this type was chosen, given that it also has 6 analog inputs for analog-to-digital converter, each with a resolution of 10 bits (2^10 = 1024 intervals) and the acquisition frequency can reach 125kHz. This paves the way for the acquisition of parameters in the process, which will correspond to further developments. This information cannot be stored in the memory of the microcontroller, as it will be transmitted to a computer system via the communication ports with which the ATMEGA 328P is endowed - especially serial communication, via the UART port. Besides, the microcontroller can also communicate with the external environment through I2C or SPI protocols.

Last but not least, was opted for this microcontroller also due to the fact that it supports a large supply voltage range of 1.8-5V which ensures good stability in conditions of disturbances in the industrial environment.

In the shown scheme, in order to command the triggering of the download, the generic port O1 was used, which is raised to the state of "1" logically for the duration for which the download is desired. The pulse duration was set in the laboratory simulations to obtain an optimal discharge, in the range of 10-50ms. Besides, the resolution allowed by the microcontroller and the programming environment is at the millisecond level, which allows great flexibility in use.

The impulse thus obtained is transmitted via limiting resistance of the current R1 to the anode of the optocoupler LED OPTO1. It was decided to introduce into the circuit the optical coupling considering the very high voltages that will be generated in the secondary transformers but also for the fact that the voltage required for the primary transformer coil Tr1 (V2) is higher compared to the microcontroller supply (5V) and for his protection.

The bright excitation of the LED in the optocoupler causes its transistor to be open for a period of time equal to that of the firm command, in the rest of the time it is not in conduction. This allows that in the absence of conduction, the voltage at the 4th pin of the optical coupling is 0V and at the moment of conduction is close to the value of V2. This is also signaled by the lighting of the D2 LED during the conduction of optocoupler used as witness.

The command voltage then reaches the MOSFET transistor gate through the resistive divider (for experiments, we chose IRF540). This transistor supports a power dissipation of approximately 50W. Also, this transistor was chosen for the drain-source resistance of only 0.077 ohms in case of maximum opening (Ugate-source = 10V), the maximum voltage supported between the drain and the source being 100V and the maximum current supported by the drain-source when driving maximums being over 20A. Such a transistor was necessary because the primary of the lifting transformer Tr 1 has a relatively low resistance. Also, in parallel with the primary transformer, a diode was mounted (in reverse direction to the current direction) to suppress the reverse voltages that occur by induction in the primary transformer when the supply voltage disappears. Also, in the source of the MOSFET type transistor, a low power value resistance was applied toward the table (in the tests a value of 0.22 ohms at 5W was used) necessary to protect the coil of the primary of the transformer that lift voltage in case the duration of the command pulse would be longer.

For V2, during the experiments, a value of 12V was used but, for the modification of the discharge parameters, by changing the secondary voltage, it can be modified, in the upper direction up to a value of 24V, the command transistor can support this without problems.

The voltage collected from the secondary of transformer Tr1 is readdressed by means of diode D4 (high voltage or several series diodes) and applied to the pair of electrodes. In the discharge electrodes also are arriving, through diode D5, the voltage obtained by accumulating electrical charges on capacitor C1. This voltage is also accompanied by a very high current, given by the almost instantaneous discharge of the capacitor C1 and necessary to obtain high temperature values for fixing the powders on the desired surface. The voltage on capacitor C1 has a much smaller order of magnitude than that obtained through the transformer Tr1, depending on the nature of the materials used, which can vary in the range of 50-350V. The set of diodes D4 and D5 prevent the high voltage obtained through the transformer Tr1 from not reaching the capacitor C1, thus protecting it from puncture.

The voltage required to charge the capacitor C1 is obtained from the electric network with the help of the transformer Tr2 and readdressed with the help of the rectifier bridge BR1. As an idea for a further development of the project, it will be opted for a controlled charging of the capacitor C1 through the microcontroller in order to be able to control the energy required to discharge the capacitor depending on the materials used.

In the scheme in figure 5, only the circuits necessary for a single pair of electrodes were represented. This can be repeated / multiplied for as many pairs of electrodes as necessary and a possible temporary gap between the electrodes can be ensured by using different ports of the microcontroller.

5. Conclusions

The development of technologies in general and information technologies in particular make it possible to adapt the machining process using IEDSR to an information system capable of rotating the work piece and moving tools with the multi-electrode system so as to produce the necessary electric discharges at the right place and the right time.

The use of stepper motors that have sufficient characteristics to perform the necessary tasks and their programmed operation, allow to obtain high resolutions of the deposited layer or to obtain several layers of deposits.

In this way we can optimize the IEDSR machining process by achieving the following objectives:

- streamlining the processing process by increasing the productivity of the process;
- obtaining surfaces with a low roughness after processing;
- obtaining electric discharges with a predetermined resolution;
- obtaining layers of predetermined thicknesses;
- considerable savings in electricity.

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