The vacuum system for technological unit development and design

A M Zhukeshov, A T Gabdullina, A U Amrenova, Sh G Giniyatova, A Kaibar, A Sundetov, K Fermakhan
Science Research Institute of Experimental and Theoretical Physics, Kazakh National University named al-Farabi, Tole bi 96 a, Almaty, 050012, Kazakhstan
e-mail: azhukeshov@gmail.com

Abstract. The paper shows results of development of plasma technological unit on the basis of accelerator of vacuum arc and automated system. During the previous years, the authors investigated the operation of pulsed plasma accelerator and developed unique technologies for hardening of materials. Principles of plasma formation in pulsed plasma accelerator were put into basis of the developed unit. Operation of the pulsed arc accelerator was investigated at different parameters of the charge. The developed vacuum system is designed for production of hi-tech plasma units in high technologies in fields of nanomaterials, mechanical and power engineering and production with high added value. Unlike integrated solutions, the system is a module one to allow its low cost, high reliability and simple maintenance. The problems of use of robots are discussed to modernize the technological process.

1. Introduction
One of actual problems of the FIID state program is replacing of import of technologies by development of home-made hi-tech units. Among various methods of vacuum-plasma surface modification, technologies of magnetron and arc treatment can be considered as the most proved ones [1]. However, they have some shortcomings, such as small treatment area, high consuming current, heating of cathodes, etc. Recently in the world, pulsed systems of plasma treatment are actively developed which promise more effective results [2]. The treatment technique is based on short power exposure of plasma flows on surface layers of material [3]. At erosion of the electrode, definite operation mode of the unit produces plasma which content corresponds to material of the electrode and allows to use this process for deposition of metal onto various materials. Some types of new composite material coatings (multi-cathodes) cannot be obtained in other ways [4]. Due to their unique abilities, pulsed technologies allow to produce new materials of specified properties and have sensible advantages over other methods [5].

During the previous years, the project performers produced various vacuum units and developed unique technologies of pulsed vacuum-arc deposition and plasma treatment. In 2009-2010, a technology was developed for production of new materials on the basis of promising method – pulsed plasma treatment of surfaces with plasma flows obtained at electrodynamic accelerators. These technologies were tested and showed high efficiency for hardening of materials and production of coatings [6-8].
The use of robots and other automation equipment in the plasma process can significantly limit or eliminate participation of the person. In many cases, it provides a significant economic effect. In addition to economic and holds social effect is the removal of a person from danger to his health and life of technological operations [9]. Furthermore, there are operations that cannot be executed by person (operation under vacuum). However, in our case application of the robot is due to operational needs. At work in vacuum for quality coatings production it is necessary to rotate the samples, since the plasma flow is typically propagated in the one direction. Planetary mechanism is applicable only for flat samples, but that is not enough for 3D-surfaces . Therefore, it is necessary to use a robot (hand-manipulator) to capture the details and its free movement in three axes. Furthermore, the plasma flow is not always even and homogeneous in density, so the distance of exposure should be chosen depending on the work mode of installation. The task of the robot is to obtain information about the current situation and the implementation of moving parts. Thus, the creation of intellectual and robotic systems is closely connected with the peculiarities of obtaining and maintaining a high vacuum, which requires developers to choose necessary innovated technical solutions.

2. Experimental device and measured methods

The vacuum installation (Figure 1) developed with technological device – vacuum arc accelerator (VAA). On this installation we experimentally researched the arc plasma flow and carried out automation process. At first, the peculiarities of using microcontrollers in vacuum systems were found out [6]. Taking into account these requirements, a control circuit was designed for the vacuum arc accelerator.

![Figure 1 The vacuum-pulsed arc accelerator.](image1)

![Figure 2 Vacuum arc discharge current map.](image2)

The unit is designed for production of refractory material coatings by arc spray deposition as well as experiments on development of dual technology using pulsed flows of plasma as the operating medium.

3. Experimental results and discussion

Pattern of plasma formation in pulsed arc discharge is a way to understand technological features of the unit operation. Investigations with use of current transformers showed that discharge current (Figure 2) is an asymmetric descending signal with the half-period order of 1 ms and consists of two oscillations of different polarities. The same signal of aperiodic type with attenuation was observed in power pulsed coaxial accelerator (further – coaxial) CPA-30. Thus, in principal, operation of pulsed arc accelerator does not differ from operation of classic coaxial, since the both of them use coaxial anode and cathode. However, whereas a coaxial with the long electrode accelerates plasma along the electrode, the VAA constricts it on the surface of the cathode and throws it into the inter-electrode space due to its own magnetic field. In this sense, plasma acceleration mechanism of these accelerators
is the same – it is electrodynamic force. Just as the coaxial, the VAA forms plasma flow with radially symmetric distribution of current, i.e. there is a fountaining pinch, in essence. Investigations showed that the arc accelerator demonstrates small amplitude of second half-period of current and there is a series of harmonic oscillations of current with gradual attenuation in the coaxial. Obviously, the difference is due to the fact that the small voltage amplitude in the VAA accelerator sharply limits the current at inverse polarity of capacitors. Besides, it is obvious that the VAA releases ignition energy in the first half-period of current oscillation, thus, plasma formation in the second half-period is complicated.

Further on, the plasma flow density in the inter-electrode space was calorimetrically measured. The Figure 3 shows the results on measurement of plasma flow energy density distribution over the cross section of the accelerator. One can see that the energy density dramatically drops with the distance from the system axis increasing. The scheme of plasma flow formation in the VAA accelerator can be explained on the basis of the plasma flow density measurements: been emitted by the cathode, the electrons move to the anode along the curved trajectories but their drift under the magnetic field shifts the current lines outside the anode. At the same time, ions emitted by the cathode and produced by volume ionization of the gas are drawn out by electric field produced due to formation of space charge region.

The carried out experiments defined current-voltage characteristics of VAA, i.e. anode current indications from anode voltage. A series of the relations was obtained at different frequencies of pulse sequence. The Figure 4 shows the data. The measurement was carried out in the voltage range of 50 - 400 V and capacity of the anode collector 500 mcF. The tests showed sustainable operation of VAA at anode voltage higher than 50 V and vacuum of 2 ·10\(^{-3}\) mm Hg. Operation of VAA was tested at frequencies of 2, 10 and 25 Hz with saturation at 50 Hz. After working the technology out, taking into account the features of different processes, the following scheme was suggested for automation of VAA unit (Figure 5).

In the scheme, microcontroller gets analog signal from vacuum sensor, calculates the vacuum level and begins pumping process sending digital code to executive mechanisms – valves, flow controller and inlet unit. When the vacuum level is achieved, the technological process timer starts on and the VAA accelerator gets powered. If emergency, unit shut down signal is sent through the digital gate of MC.
Let us consider the concept of the control unit of the executive mechanisms (EM valves, vacuum pumps, inlet valves) in the Figure 5. To match microcontroller outlets and RES-22 electromagnetic relays were chosen. Those relays operate at voltage of 20-24 V and are powered directly by emitter followers of output transistors of digital gates of the microcontroller, thus improving compatibility. In its turn, the microcontroller is connected to Pad via Bluetooth adapter. The manual control is performed by mnemonic menu on the screen of the Pad. Further, work was performed on automation of the vacuum gauge pressure indicators. Vacuum sensor analog signal with the voltage of 0÷10 V was sent to the microcontroller ADC gate and followed by data program linearization according to the formula from the sensor manual. As a result, the Pad screen shows current value of pressure in the vacuum camera as a degree of ten.

4. Conclusions

Thus, there can be made the following conclusions on operation of the vacuum arc unit: the discharge current of vacuum arc accelerator is a double pulse of the current representing the sharp maximum in the first half-period with duration order of 1 ms and the second flatter maximum that can be explained by the VAA ignition feature; the plasma develops over the fanlike trajectory away from the central electrode and the maximal density of the energy is accumulated along the system axis in the form of Gaussian. Along with this, the diameter of the exhibited sample should not exceed the half diameter of the anode to effectively use the plasma energy. The tests showed sustainable operation of VAA at the anode voltage over 50 V and operating currents of 50-70 A with the vacuum up to $2 \cdot 10^{-3}$ mm Hg. However, operation of VAA at the frequencies over 50 Hz is undesirable because of sharp increase of the current.

References
[1] Lieberman M A, Lichtenberg A G 1994 John Wiley & Sons Inc., New York 450
[2] Piekoszewski J et al. 2000 Nucleonica. 45 (3)193-197
[3] Tereshin V I et al. 2002 Rev. Sci. Instrum. 73 (2) 1-3
[4] Yan P X, Yang S Z, Li B. and Chen X S. 1996 J. Vac. Sci. Technol A. 14 (1) 115-117
[5] Chebotarev V V, Garkusha I E, Langner J et al. 1999 Problems of atomic science and technology. Series: Plasma physics. 3(3) 273-275
[6] Zhukeshov A.M., Gabdullina A.T., Amrenova A.U e. a. 2013 Mat. Sci. Appl. 4. 35-41
[7] Zhukeshov A M, Amrenova A U, Gabdullina A T 2013 Int. J. Mat. Sci. Appl. 3 (2) 115-119
[8] Zhukeshov A M, Amrenova A U, Gabdullina A T, et al. 2013 American J. Phys. App 1 5-9
[9] Bobrow J E, Dubowsky S, and Gibson J S 1985 Int. J. Robotic Research. 4(3) 3-17.