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ELECTROMECHANICAL MEASURING UNIT OF ELECTRON BEAM DIAGNOSTICS APPARATUS

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In this paper, we formulate a list of the main characteristics of the electron beam responsible for its technological properties and to be diagnosed, and propose the design of the electromechanical unit of the developed system that diagnoses the parameters of electron beams formed in electron-optical systems based on plasma emitters.

Introduction. Expanding the possibilities of industrial application of plasma emitter-based beam devices requires solving a number of theoretical and practical problems. In particular, scientific and practical interest is the development of electron-optical systems (EOS) of such a design that would provide maximum efficiency by reducing the beam divergence in the region of its primary formation, i.e. a search is required for the optimal geometry of the electrodes of the gas-discharge structure and the accelerating gap [1].

To optimize the EOS, it is advisable to use the parameters of the electron beams responsible for its quality: the beam divergence, its brightness, and generalizing these characteristics are emittance [2]. In turn, for their measurement, it is necessary to develop diagnostic equipment. Moreover, for the automatic processing of information (construction of three-dimensional surfaces, determination of the phase portrait of the beam, calculation of emittance and brightness), it is necessary to develop appropriate software. A similar complex, including an electromechanical device, a control system and a software package, can be used not only to optimize the designs of plasma sources under development, but also other beam devices in order to increase their technological efficiency and beam quality.

In this paper, a list of the main characteristics of the electron beam, responsible for its technological properties and subject to diagnosis, is formulated and the design of the electromechanical unit of the developed diagnostic system is proposed.

Physicotechnical parameters for evaluating the technological capabilities of electron beams. Plasma electron sources should provide the parameters that are necessary for the implementation of certain modes of electron beam exposure. These parameters include the following:

– emission current density;
– energy efficiency associated with the efficiency of switching the electronic component of the discharge current forming the emitting plasma into the beam;
– the value of the flow (pressure) of the plasma-forming gas.

Emission current density – j_e depends on the plasma density (value of the discharge current) and the result of the superposition of the field of the parietal layer with the length of the layer l_l in the emission channel of radius r_0 and the field of the accelerating electrode. In the near-wall layer, a negative (potential inhibiting for electrons) drop in potential is usually realized, and for $l_l > r_0$ the electrons leave the plasma in the accelerating gap through the potential barrier. The accelerating field penetrating the emission channel(s) reduces the potential barrier for electrons and, accordingly, increases the density of the emission current. In this case, the emission of electrons is carried out from the open plasma boundary, and then the emission current density becomes equal to the density of the thermal current of the electrons in the plasma, significantly exceeding the current density to the electrodes of the discharge chamber (discharge current). When the field of the accelerating electrode penetrates the discharge chamber through the emission channel, the emitting plasma surface may exceed the area of the emission channel. In this case, a beam crossover is formed in the channel, in which the current density is higher than the density in the plasma.

Extraction efficiency – $\alpha = i_e/i_d$ characterizes the degree of electron switching into the emission channel(s). There i_e emission current (in PES coinciding with the beam current), i_d – discharge current.

Energy efficiency (energy price of an electron in a beam). The parameter characterizes the efficiency of the plasma emitter and is determined by the ratio $H_Э = \frac{i_e}{P} = \frac{\alpha}{U_d}$, where P – power spent on plasma formation (discharge power); U_d – discharge voltage.

For plasma emitters operating in stationary mode, the energy efficiency is comparable to or slightly higher than the value for thermal cathodes ($H_э = 10^{-2} – 10^{-3}$). In a pulsed mode with a sufficiently large duty cycle (when using pulsed discharges in PES), the energy efficiency increases by orders of magnitude [3].

The value of the flow rate of the plasma-forming gas *Q* characterizes the gas efficiency of the PIEL and is determined by the necessary pressure in the gas-discharge structure, at which the plasma with the necessary parameters is formed. Since the final element of the gas-dynamic system providing gas inlet is the emission channel through which gas enters the accelerating gap, the maximum value of *Q* is determined by the required electric strength of the electron beam acceleration gap.

Complex characteristics of electron beams. When assessing the technological suitability of an electron beam for the implementation of a specific technological process, as a rule, they are limited to comparing the density of the beam power and the electron energy in the beam ($p = jU$ and $W_e = eU$, where *j* – beam current density, *U* – accelerating voltage) with required parameters [4]. However, at the stage of designing electron-beam devices, optimizing the geometry of the EOS to increase the efficiency of the electron gun in specific gas-dynamic conditions, as well as developing new technologies, it becomes necessary to obtain, compare, and correct as more specific parameters (divergence, current density distribution, electron plasma temperature, maximum beam diameter), as well as complex characteristics that allow you to compare beams (emittance, brightness) by determining their quality. To evaluate each of the particular characteristics, there are developed methods that allow them to be studied depending on external conditions. However, all these parameters are interconnected and a change in one leads to a change in the other. This situation makes it difficult to compare the quality of the beams based on one of the parameters. Therefore, to obtain an integral characteristic of the quality of the beam and their comparative analysis, it is advisable to use complex characteristics, which, in particular, include the following:

Beam brightness - the value corresponding to the beam current, which passes into a unit solid angle, based on a unit area $B = \dfrac{dI}{d\Omega dS}$, where $d\Omega$ – solid angle at which the beam passes, dS – area on which the solid angle rests.

Another complex characteristic of the beam is emittance. In a first approximation, the emittance is the area of the phase portrait of the electron beam in the plane (x, x ') and / or, if necessary, in the plane (y, y'), if the beam does not have radial symmetry. If x and y coordinates are in the plane perpendicular to the direction of beam propagation (z axis), and x 'and y' are the components of the radial velocity of the electron beam, which determine the beam divergence ($\Delta\Theta_{x,y}$) in the xz and yz planes, respectively, the emittance can be determined by the following expressions

$$Э_x = \frac{1}{\pi}\int dxdx' \qquad Э_y = \frac{1}{\pi}\int dydy' \quad Э_z = Э_x Э_y$$

If the phase portrait is an ellipse, then the brightness and emittance are interconnected by the ratio $B = \dfrac{dI}{d\Omega dS} \approx \dfrac{I}{(\pi\Delta r^2)(\pi\Delta\Theta^2)} \approx \dfrac{I}{\pi(x_0 x_0')\pi(y_0 y_0')} = \dfrac{I}{\pi^4 Э_x Э_y}$. To estimate the brightness of an axisymmetric beam, one can use the expression $B = \dfrac{I}{\pi^4 Э_x^2}$

The beam divergence angle can be estimated as $\Delta\Theta = x'_{\max} = \dfrac{\bar{\upsilon}_x}{\upsilon_z} = \dfrac{1}{\upsilon_z}\sqrt{\dfrac{2kT_e}{\pi m_e}} = \sqrt{\dfrac{2kT_e}{\pi m_e \upsilon_z^2}} = \sqrt{\dfrac{kT_e}{\pi e U_{уск}}}$, where T_e – electron temperature in electron volts, which can be defined as: $kT_e = \pi e U x'^2_{\max}$

Of greatest interest are three-dimensional surfaces constructed by measuring emittance. Such surfaces make it possible to effectively conduct visual comparisons of the quality of the beams when any external parameters change, and also to calculate most of the parameters of the electron beams (divergence, diameter, current density distribution, etc.). However, to build three-dimensional surfaces, it is necessary to provide storage and processing of a large amount of information, as well as high speed of its reading. Therefore, to carry out such measurements, it is necessary to develop and produce diagnostic equipment that allows one to construct a three-dimensional image of the phase volume of the beam, determine the beam diameter in a certain plane, the divergence, emittance, brightness, and a number of additional parameters. The structural diagram of the developed diagnostic complex can be represented as follows (Figure 1).

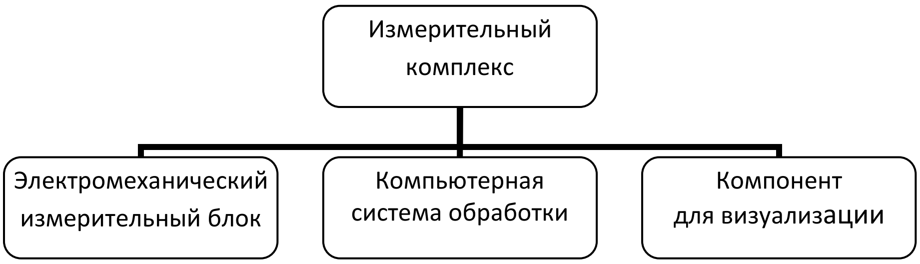
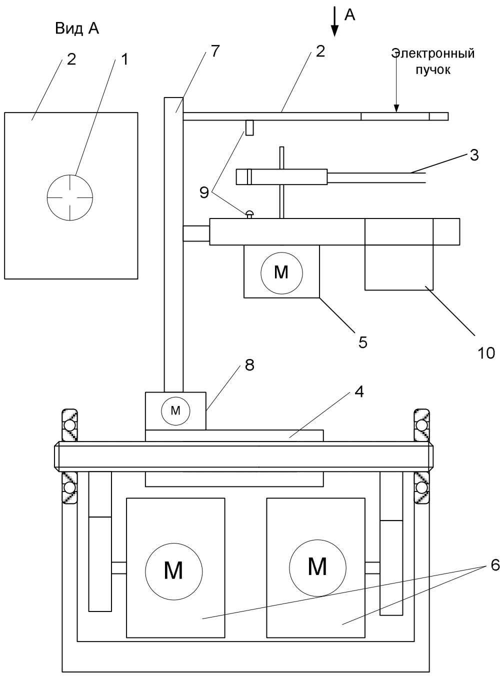


Figure 1. - Block diagram of the measuring complex

Electromechanical measuring unit. There are various methods and devices for measuring the parameters of an electron beam. Most of them contain sensors that are in direct contact with the electron beam. A thin wire [5], periodically crossing the beam, or a collector, which receives a part of the beam separated by a narrow slit, a calibrated hole, or by the straight edge of the refractory plate, can act as a sensor [5]. The sensors make it possible to obtain a current distribution in the selected part of the beam. This distribution contains information about the geometry of the electron beam, current density and power density in it, brightness and angle of convergence. Having such a set of beam data, based on the above relations, it is not difficult to establish the relationship between the beam parameters and the characteristics of the electron gun. The listed types of sensors are very similar in the way of obtaining primary information about the beam. However, there is a fundamental difference between the two. All sensors, except for a rotating probe, use to deviate or scan the beam along the required path to obtain a probe. The trajectory of the electron beam is determined by electromagnetic deflecting systems. When studying powerful focused electron beams, the contact time of the beam with the elements of the beam diagnostic system should be as short as possible. This is to prevent damage to the diagnostic device. Therefore, the deflecting coils of the gun must be high speed. In addition, additional difficulties may arise if it is necessary to measure the parameters of the beams at small distances from the deflecting coils. In such cases, the deflection angles may be unacceptably large due to possible beam distortion introduced by the deflecting coils. Creating such coils is a rather difficult task.

This paper presents one of the possible options for implementing the contact diagnostic method, in which there is no need to deflect the electron beam to measure its parameters. As a sensor, a wire double rotating probe was chosen.

The block diagram of the electromechanical unit is shown in Figure 2. The principle of operation of such a unit is as follows: the electron beam from the source passing through the positioning system sensor generates a signal to the PLC (industrial logic controller, not shown in the figure), the control signal from which is supplied to the positioning system motors and centering the equipment. Under the plate is a sensor, which is a system of two scanning probes 3, spaced vertically in space and offset by an angle relative to each other. A wire made of refractory material (nichrome, tungsten) with a diameter of about 0.1 mm and a length of 50 mm is used as sensor material. This choice is due to the criteria of heat resistance (heating up to 1000 K), mechanical strength and stiffness to prevent sagging during engine shutdown and acceleration. The probes are rigidly attached to the disk. The disk is necessary to protect the engine from exposure to the electron beam, so the diameter of the disk is larger than the diameter of the engine. The disk and the motor axis are isolated from each other. The diameter of the disk and the length of the probe are selected so that in the working area the position of the probe can be considered parallel to the centering hole through which the electron beam passes. To remove current, a needle is fixed in the center of the disk, the other end of which is gently connected to the spring-loaded current collection plate. This design does not additionally load the engine and avoids contact bounce, as the needle rotates at one point in soft metal (tin). The probe system is rotationally driven by the engine 5. The engine and plate are mounted on the shaft 7 and can be moved vertically. The rotation control and signal transmission of the measured parameters is carried out by means of a PLC. The beam is received in a grounded water-cooled Faraday cylinder.



1 - positioning system sensor; 2 - plate; 3 - system of a double scanning probe; 4 - two-position coordinate table;
5 - rotation motor; 6 - positioning engines; 7 - shaft vertical movement; 8 - engine vertical movement;
9 - optocoupler; 10 - Faraday Cylinder

Figure 2. - Structure of the electromechanical unit of the diagnostic equipment

Conclusion. The presented electromechanical unit allows you to automatically remove the current distribution to the probe and translate it and the main characteristics of the electron beam into the software environment to calculate the required characteristics and visualize the measured parameters and can be a prototype for the development of industrial systems for diagnosing the parameters of electron beams.

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