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Low-energy Electron Beam Profile Monitor

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A low-energy electron beam profile monitor has been developed and tested. It has been used to optimize the focusing of continuous electron beam of current up to 5 mkA and kinetic energy less than 20 eV. The device realizes the pin-hole camera method. The beam-sampling part of monitor is based on Nipkow disc principle, which allows investigating the beam cross section for one complete turnover. This made it possible to accelerate the measurement process in comparison with devices using the reciprocating movement of a collector with a hole. The monitor enables the determination of two-dimensional beam profile and measurement of beam current. The monitor was used to study the parameters of a low-energy electron beam gun designed to measure the work function of electrons from a metal by the Anderson method. The scheme is given and the operation of the experimental setup is described. The electrical signals received in the process of scanning together with synchronization pulses through the PCI-1802L adapter are transmitted to a personal computer, where a specially developed program collects and processes the received data. The measurement results are displayed on the computer monitor as a family of line graphs, 3*D* images and tables for each measurement cycle (disk turnover). The design incorporates low material and labor costs and minimal amount of devoted electronics.

Keywords: Electron gun, Beam profile, Electron collector, Work function, Anderson method.

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1. INTRODUCTION

For measuring the electron work function of a metal according to the Anderson method [1] we developed an electron gun with electron energy of less than 20 eV. For the successful application of this gun, it is necessary to ensure a high quality of electron beam focusing on the surface of the sample under study. Focus quality control with the fluorescent screen in our case is impossible without post acceleration of electrons. Another possibility to determine the beam size and evaluate its quality is to use the so-called beam profile monitor. Beam profile monitors are widely used to monitor and measure the parameters of ion and electron beams [2-5]. From the known variety of methods, we dwelt on the pin-hole camera method [6]. This method is attractive due to the relative ease of implementation of measurements and processing of the obtained results. In addition, it is well suited for the study of low-current low-energy electron beams with a small cross section.

The essence of the pin-hole camera method is the sequential decomposition (using a movable hole) of the electron beam cross section into small elements and the measurement of currents of these elements. The dependence of the current passing through the hole as a function of the hole location (center coordinates) found in this way will determine the distribution function of the current density along the line of movement of the hole. In this way, current density distributions in various sections of the electron beam, the sizes of these sections, etc. can be found. Obviously, for operational work with the beam under study, it is necessary to ensure the monitor as fast as possible. From this point of view, the idea of scanning the beam cross section with the help of the Nipkow disk in an ion beam monitor [7] seems to be very interesting.

A Nipkow disk, also known as a scanning disk, is a mechanical, rotating, geometrically operating image scanning device patented in 1885 by Paul Nipkow. This scanning disk was a fundamental component in mechanical television up to the invention of receiving and transmitting electron-beam tubes. The device is a mechanical spinning disk of any opaque material, with a series holes of equal diameter drilled in it. These holes are positioned to form a single-turn spiral starting from an external radial point of the disk and proceeding to the center of the disk. When the disk rotates, the holes trace circular trajectories, with radii depending on each hole position on the disk. Holes pass through the study area alternately. As a result, the object under study will be scanned line by line from top to bottom for one complete disk turnover. It is clear that the scan time can be made significantly shorter than with reciprocating movement of the collector with the hole.

This paper presents the results of the development of a high-speed beam profile monitor with a scanning system in the form of a Nipkow metal disk. The developed device was successfully used to study the profile of a low-energy electron beam gun.

2. ELEMENTS AND SCHEMES OF EXPERIMENTAL RESEARCHES

2.1 Beam Profile Monitor Design

The use of a beam profile monitor in our case has some peculiarities. The stage of direct measurements, as a rule, is preceded by the procedure for tuning the gun to a maximum current. It consists in changing the power supply parameters of the gun (heating current, focusing voltages, etc.). The need for periodic adjustment is due, in particular, to the fact that during operation, a deposit

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is formed on the gun electrodes as result of interaction of the electron beam with residual gases.

The variant of the Nipkow disk developed by us is schematically shown in Fig. 1. The disk is made of brass with a thickness of 0.5 mm and has an outer diameter of 65 mm. Hole at the top of the disk in Fig. 1, used when adjusting the gun, has a diameter of 10 mm. It passes a beam of electrons to the receiver, regardless of the quality of its focusing. This hole determines the angular size of the measuring sectors equal to 22.5° and their amount accounts 16.

In order to eliminate interference from transient processes during the transition from the tuning mode to the beam profile measurement mode, the sectors adjacent to the tuning hole are not involved in the measurement. Thus, the actual working sectors remain 13, which allows us to form, respectively, 13 raster lines with one revolution of the disk.

At the boundaries of the working sectors, there are holes with a diameter of 0.8 mm with a shift of 0.75 mm along the radius of the disk. In the process of turning the disk to 22.5°, every hole passes from one border of the measuring sector to the other. Since the holes are displaced along the radius of the disk, a "frame" consisting of 13 lines is formed in one turn, and covering a part of the measuring sector, about 10 mm high. The frame layout is indicated in Fig. 1 by dashed lines.

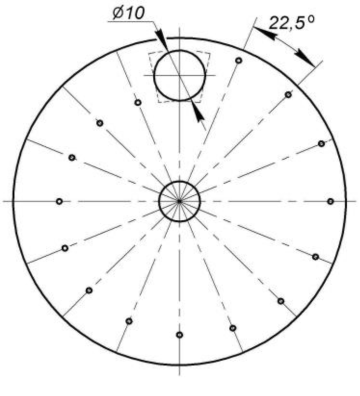


Fig. 1 – Nipkow disk for beam profile meter

2.2 Installation for Measuring Current Beam Profile

To check the operation quality of the developed beam profile monitor, an experimental setup was assembled, on which the electron gun was examined. This gun was designed to determine the electron work function by the Anderson method. The block diagram of the measuring installation is presented in Fig. 2.

The design of the studied gun and its characteristics are close to the gun described in [4]. The main distinctive feature of such a device is a steep initial part of the volt-ampere characteristic. When studying the beam parameters, the gun operates at a distance from the initial part of the characteristic closer to the saturation region, where in the continuous mode the current stability is quite high. The gun uses a tungsten filament wire. The whole filament mounting block is used from an electron microscope. This made it possible to use standard replaceable cathode inserts without problems.

The main gun-forming electrodes: the Wehnelt electrode; pulling diaphragm; electrostatic focusing lens; collector of electrons reflected from the sample. The diameters of the holes for the passage of the electron beam are 1.5 mm. The output electrode (the collector of electrons reflected from the sample) is a cylindrical tube 15 mm long with an inner diameter of 3 mm. A disk with a diameter of 30 mm is located at the output end of the collector.

The Nipkow disk is located at a distance of 10 mm from the end of the gun. The electron beam coming out of the gun passes through the holes in the disk and enters the electron receiver in the form of a Faraday cylinder. The diameter of the entrance aperture of the latter (about 15 mm) allows to register electrons within the entire scanned frame.

On the same axis with the main measuring disk, the synchronization disk is fixed, also divided into 16 sectors. At the boundaries of the sectors, narrow (about 0.5 mm) slots are cut, with the help of which horizontal sync pulses are formed. It allows us to get a steady "image" of the beam cross section on the computer monitor.

The received signal is fed to the current amplifier, made according to the current-voltage converter circuit. This device, which has a low (close to zero) input resistance with a large conversion factor (10^7 A/V), makes it possible to reliably detect currents of less than1 μA, practically eliminates the influence of the sample potential on the measurements, and is less sensitive to external interference and tips. Next, the signal is transmitted to the PCI-1802L analog data acquisition card, coupled to a personal computer, and also enters a digital oscilloscope to control the measurement process. The driver of synchronization pulses is located near the synchronization disk. It consists of an LED and a photodiode, arranged so that the light on the LED will only fall when a slot on the disk passes between them. The final formation of synchro-pulses is performed by a special electronic circuit from which they are fed to the current-voltage converter, where they are mixed into the registered signal.

The electron gun, beam profile monitor, Faraday cup, and sync driver are located in a vacuum chamber. It is pumped out by a turbomolecular pump to a pressure of about 10^{-5} Pa.

3. RESULTS OF MEASUREMENTS AND THEIR ANALYSIS

When the holes of the Nipkow rotating disk begin to cross the electron beam emerging from the gun, the bell-shaped pulses, varied in amplitude, appear at the current-voltage output of the converter. The width of the pulses characterizes the size of the cross section along the measuring line, and by the change in the amplitude of the pulses, it is possible to judge the beam profile with the height of the frame.

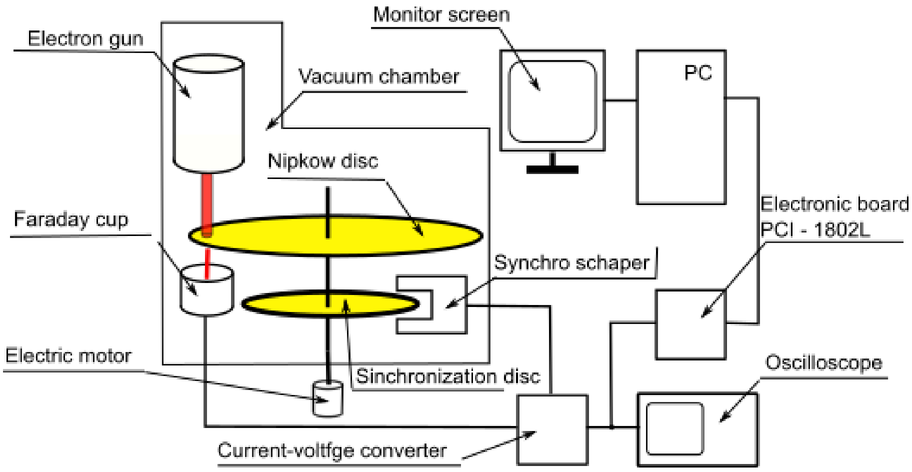


Fig. 2 – Block diagram of the installation for measuring the current beam profile

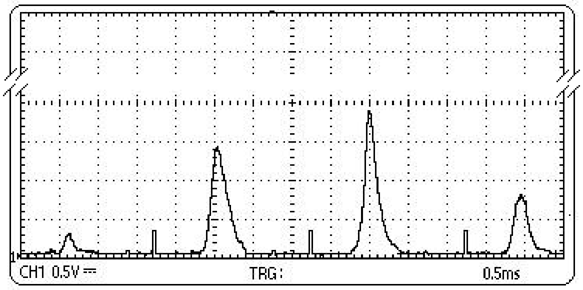


Fig. 3 – Control waveform when measuring the beam profile

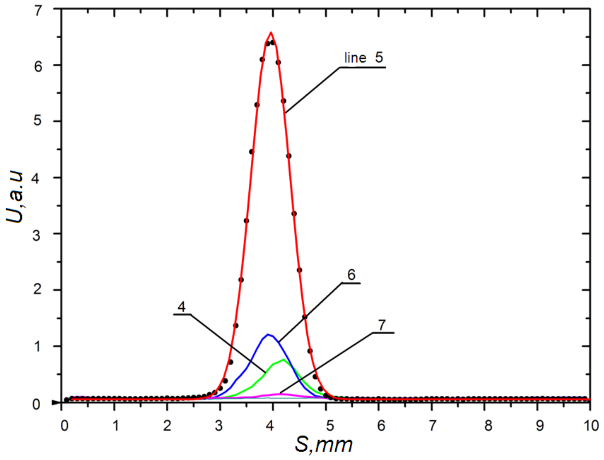


Fig. 4 – The results of measuring the current profile for a focused electron beam

Fig. 4 shows the beam profiles along the lines of the cross section for the case of its optimal focusing. It can be seen from this figure that the size of the spot, which bounds the beam, is about 2 mm.

This cross-sectional size can be considered typical for low-energy guns [8]. Accordingly, in the perpendicular direction, a noticeable signal is present only on lines from 4 to 7, which is confirmed by the control oscillogram in Fig. 3. It should be noted that the graph corresponding to line 5 is represented by experimental points on which an approximating curve is imposed, corresponding to the Gauss function. It can be seen that the points fit this dependence very well. Fig. 5 shows the profile corresponding to the chord along the height of the “frame”. This profile is also well described by the Gauss function, and the characteristic beam size practically coincides with Fig 4.

This result is a consequence of the axial symmetry of the formed beam and confirms the sufficiently high accuracy of the results obtained using the developed beam profile monitor.

Fig. 6 shows the current profiles along the horizontal chords of the cross section for the case of a defocused beam.

It can be seen that the beam has noticeably blurred. The spot covers an area with a diameter of more than five millimeters. Accordingly, lines from five to ten are involved in the perpendicular direction.

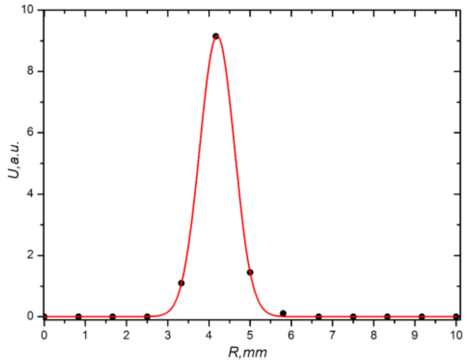


Fig. 5 – The current profile of the beam along the height of the "frame" with optimal focusing

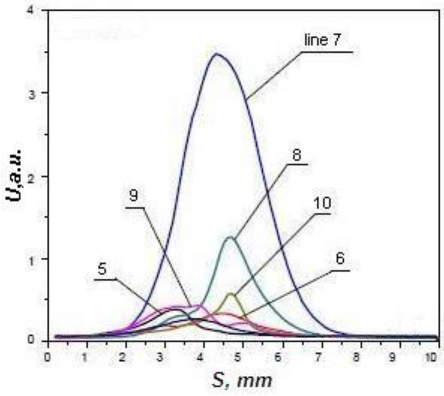
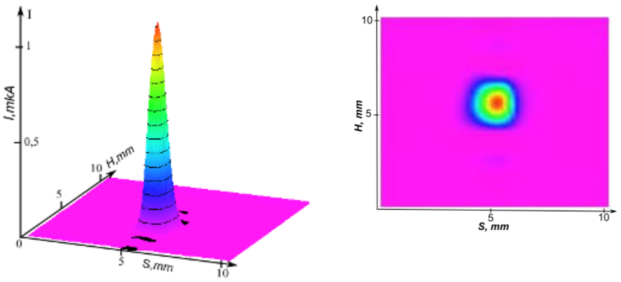


Fig. 6 – Line profiles for defocused beam

When constructing the above graphs, some simplifications are taken. In particular, cambered lines are replaced by straight segments of the same length. As a result, the “frame” acquired a rectangular shape. This simplification did not lead to substantial distortions due to the fact that the beam cross section occupies only a small part of the scanned area.

Fig. 7a shows the calculated 3D relief of the electron beam current obtained using the MAPLE 14 program. It satisfactorily corresponds to the two-dimensional profiles given above for the case of optimal focusing. Fig. 7b shows another angle of observation of the beam relief (along the current axis), showing the size and shape of the trace (spot) of the electron beam on the target. Thus, we have the information that the beams of greater energy are obtained using a fluorescent screen.



a b

Fig. 7 – 3D current relief (a) and current spot (b) of the electron beam under study

Experiments have shown that, despite the simplicity of the device, the monitor has a fairly high efficiency. After each turn of the Nipkow disc, which lasts about 5 s, images similar to those in Fig. 5 and Fig. 6 are displayed on the computer screen. Moreover, the 3*D* image of the beam current can be rotated by choosing a convenient viewing angle. This turned out to be very useful when tuning an electronic gun in the optimal mode.

4. CONCLUSIONS

The monitor of the current profile of the electron beam on the basis of the Nipkow disk was developed, manufactured and tested under real experimental conditions. The low-energy electron gun developed for measuring the work function of electrons from metals by the Anderson method served as the measurement object. The experimental setup of the monitor investigation and the measurement procedure are described. The developed software allows us to get all the necessary information during one measurement cycle (full disk turnover). Two-dimensional profiles of the generated electron beam are studied at various gun modes. The beam profile monitor showed good performance and made it possible to obtain valuable information about the parameters of the electron beam and develop a method for optimal adjusting the gun modes. The measurements showed that the real characteristics of the developed gun allow it to be successfully applied to measure the electron work function according to the Anderson method.

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Монітор профілю низькоенергетичного електронного пучка

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Розроблений та протестований монітор профілю електронного пучка з низькою енергією. Він був використаний для оптимізації фокусування безперервного електронного пучка зі струмом до 5 мкА й кінетичною енергією менше 20 еВ. Пристрій реалізує метод колектора з малим отвором. Колектор електронів виконаний на принципі диска Нипкова, який дозволяє досліджувати поперечний переріз за один повний оберт. Це дозволило прискорити процес виміру у порівнянні з приладами, що використовують зворотно-поступальний рух колектора з отвором. Монітор дозволяє визначати двовимірний профіль променю й вимірювати його струм. Монітор використовувався для дослідження параметрів пучка низькоенергетичної електронної гармати, призначеної для виміру роботи виходу електронів з металу за методом Андерсона. Наведена схема експериментальної установки для тестування монітора й описана її робота. Електричні сигнали, отримані в процесі сканування, разом з імпульсами синхронізації через адаптер PCI-1802L передаються на персональний комп'ютер, де спеціально розроблена програма збирає й обробляє отримані дані. Результати вимірів відображаються на моніторі комп'ютера у вигляді сімейства лінійних графіків, тривимірних зображень і таблиць для кожного циклу виміру (оберту диска). Конструкція потребує невисоких матеріальних й трудових витрат й мінімальної кількості спеціальної електроніки.

Ключові слова: Електронна гармата, Профіль пучка, Колектор електронів, Робота виходу, Метод Андерсона.