Modernization of the electron accelerator “Calamary” facility diagnostic complex to apply optical methods for plasma and shockwave processes investigation.

S S Ananyev¹, B A Demidov¹, E D Kazakov¹,², Yu G Kalinin¹, A A Kurilo¹,², M G Strizhakov¹ and A Yu Shashkov¹
¹ National research center “Kurchatov Institute”
² National research University “MPEI”

Kazakoved82@gmail.com

Abstract. When studying the interaction of a high-current electron beam with a solid target, one of the most important aspects is the investigation of the dynamics of a diode plasma, which results from the powerful pulsed energy deposition in its surface layers. In connection with the fact that the appearance in the target of a mechanical recoil pulse and the formation of a shock wave in it depend significantly on the dispersion of matter from the surface, it is necessary to know not only the mass of the evaporated matter, but also the speed of its expansion. In this work we propose an absolutely new complex approach to the study of plasma dynamics and shock wave processes in transparent targets, which will allow a substantial increase in the amount of information on both plasma and shock wave processes in the interaction of a beam with a target. New optical scheme and a synchronization system are proposed. It is possible to use a laser probe system in the shadow or schlieren mode of photography.

1. Introduction
Experiments on the interaction of high-current electron beams with polymer and composite materials are carried out on a high-current Calamary electron accelerator (see, for example, [1, 2]). Investigation of the impulse impact on such materials is of great practical importance, since such materials are actively used in aerospace engineering, as well as in laboratory experiments as protective screens. Previously, a number of experiments on the Calamary facility used separate optical diagnostics [3, 4]. In this paper, we propose a new optical scheme that allows us to simultaneously use various optical diagnostics and correctly compare the results obtained.

The fundamental difference between the new optical scheme and those used earlier is that radiation from the investigated area is built by one lens for various recorders and various diagnostics. So from one direction, one registers its own radiation in the visible region in the mode of high-speed photography and also slit chronography (streak). In addition, from the same direction, a shadow image is constructed on the second harmonic of the YaG: Nd laser also in the multi-frame and streak modes. Transferring images to all recorders is done with a single scale (1:1), which greatly simplifies the adjustment and alignment of the optical circuit.
2. Experimental setup

Figure 1 shows the registration scheme. The image of the diode unit 1 of the Calamary accelerator 2 is constructed by the lens 3 with the help of beam-splitting elements 4 on the photocathodes of electron-optical recorders operating in the streak mode 5 and high-speed photography 6 and 7. From the screens of the electron-optical converters (EOS) of all recorders, the image is read using digital photo set-top boxes 8 based on SLR digital cameras [5].

For the convenience of placing the equipment, an additional lens 9 was used. In addition to allowing the image of the process to be visualized at a convenient location in the optical bench, the registrar 6 (three-frame high-speed camera) was also able to use a field of view that was twice as small as the rest [6]. Shadow images are formed in the radiation of the main 10 or alignment 11 lasers operating in a continuous mode and equipped with a mechanical shutter with electronic triggering for synchronization. To separate the laser radiation from the intrinsic radiation of the plasma, an interference mirror is used. 12. The frame images in the laser shadow are formed on the photocathodes of six image intensifier tubes of the recorder 7 by means of a beam-splitting system (for simplicity, only the upper row of the image intensifier is shown in Fig. This registrar allows you to create a sequence of frames by launching the electron-optical converter (EOC) with various delays between frames [7]. This scheme allowed to place all optical elements rather compactly and removing them from the facility. Recording equipment is installed on two parallel optical benches and equipped with movable tables for adjustment and metal shielding boxes galvanically separated from the ground (Fig. 2).
Figure 2. Location of elements of optical diagnostics. Electron-optical recorders with delay lines are installed on the bench. In the foreground is a personnel recorder with a generator for the formation of a high-voltage power supply pulse and a delay line. On the right is a lens with a diaphragm.

As light-dividing elements, semitransparent mirrors with antireflective coatings and anti-reflective coatings are used, as well as glass prisms. Mirrors of the laser path are multilayered. Laser generators are placed in an adjacent room with an experimental hall and placed on an optical bench (Figure 3).

Figure 3. Diagnostic and aligning laser generators in a room adjacent to the experimental hall, placed on an optical bench. Shown with the cover removed.

Mirrors located in the immediate vicinity of the facility are installed on an optical rail that is not connected to the facility shell for the absence of an impact of its operation on the registration process. To increase the area of the laser beam, a telescope consisting of two lenses fixed on the same optical rail is used. See figure 4.

The vacuum chamber containing the diode unit is equipped with optical windows for input and output of the laser radiation and the intrinsic radiation of the plasma. The geometry of the diode anode assembly is optimized for the new diagnostics and allows recording both the formation of the interelectrode plasma and the dynamics of the shock wave in the target material without additional tuning.
As registrars working in the streak mode, the proven SFER-6 and FR-7 are used. The first one is used to record its own radiation, the second - to use a laser shadow. Time-analyzing slit SFER-6 is moved out of its housing and is located on the alignment table. The image is transferred to the photocathode by means of a Jupiter -3 lens with a scale of 1: 1. FR-7 has a built-in slit, the image of which is transferred to the photocathode by means of a lens.

To power the image intensifier of the frame recorder (in Fig. 1 is denoted by the numeral 7), a high-voltage pulse generator is used, assembled according to the Blumlein double-line scheme. The duration of the power pulse at half-height is 5 ns. The EOC of the recorder is grouped into three pieces (two rows placed one on top of the other) and are triggered independently of the two outputs of the generator and have a serial coaxial connection that allows adjusting the delay between frames from 10ns by introducing cable delay lines. Starting from different outputs of the generator allows you to arbitrarily change the values of delays between the image intensifier and, at the same time, to have a minimum amplitude drop of the signal during a sequential passage from the first EOC to the third one.

To synchronize all the recorders with the process under investigation, a scheme was used, including Rogowski shunts to form individual trigger signals for all recorders, as well as cable delay lines and a shielded rack with a triggering generator in an adjacent room. All diagnostic paths are made with a coaxial cable and are untied with both the facility ground and the earths of the shielding shells of the recorders. In the diagnostic cabin of the facility, multichannel digital oscilloscopes are placed for electrical measurements, as well as recording of synchronization signals from all recorders.

Using a laser level during the assembly and alignment of the optical circuit, it was possible to place all of its elements in such a way as to ensure maximum parallelism of the optical axes of all four diagnostics. This greatly simplifies the operation of the diagnostic complex. The formation of images of the investigated process on the same scale and from one direction in conjunction with the digital registration of diagnostic data made it easy to compare the results of various diagnostics for carrying out a complex analysis of the observed phenomena.

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