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Analyzer of high-load electron beams with resolution in two energy components, space and time

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Abstract

The new apparatus is developed for experimental determination of electron energy and spatial distributions in dense medium-energy long-pulsed magnetically confined beams – typically, 10 A/cm^2, 60 keV, 100 µs, 0.1 T. To provide most detailed and unambiguous information, direct electrostatic cut-off method is used for electron energy analysis. In combination with variation of the magnetic field in the analysis area, this method allows to determine both (axial and transverse) components of electron energy. Test experiments confirmed ~1% energy resolution being predicted from calculations, accounting for electrode shapes, space-charge effects and non-adiabatic energy transfer effects in varied magnetic field. Space and time resolution of the apparatus are determined by the input aperture size (~1 mm) and cut-off electric field pulse-length (~5–10 µs) respectively.

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1. Introduction

Diagnostics of dense long-pulse electron beams, being necessary for their successful utilization, represents a serious problem because of high energy density carried by the beam and transferred to any irradiated surface. This may (and often does) entail development of rather complicated phenomena, affecting the measurements, such as generation of plasmas and secondary particle flows, both in the beam facility and in the diagnostic apparatus. Thus, minimization of such parasitic effects must be among the primary purposes for diagnostic systems' design.

In our Case, the objective of further improvement of material processing techniques at GESA-series material-treatment electron beam facilities [1] required accurate measurement of electron energy distributions at the target, with resolution in position over the beam cross-section and in time within the facility current pulse. Typical GESA electron beam parameters are the following: an electron acceleration voltage U_0 = 60–400 kV, a beam current at the target is of 50–500 A corresponding to a current density up to 10 A/cm^2, a guiding magnetic field at the target B_0 = 0.02–0.10 T, an operation in single pulses with a duration of 10–100 µs. The new "Soffron60" electron beam analyzer was specially designed for operation at these conditions, near the lower limit of U_0. It was intended to supplement the "wells" measurement technique [2], installed earlier and providing very operative though rather generalized

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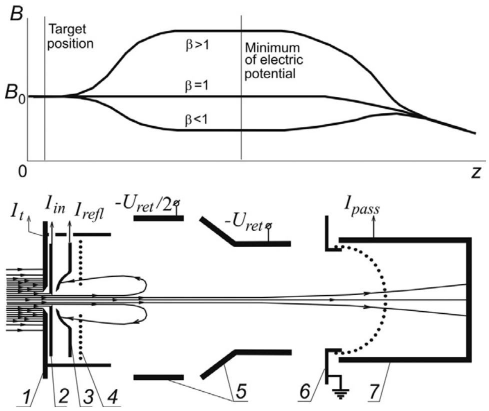

Fig. 1. Electron-optical scheme of Soffron60 analyzer: a target with input aperture (1), input current probe (2), collector of reflected electrons (3); mesh shields (4, 6), retarding field electrodes (5), passing current probe (7). The plot at the top represents possible distributions of magnetic field in the analyzer for three values of magnetization ratio β. I_{in}, I_{refl}, I_{pass} are input, reflected and passing probe currents; $-U_{\mathrm{ret}}$ is the negative potential applied to retarding field electrodes.

data on electron energy distribution parameters – in most cases, only the mean pitch angle of electron trajectories.

2. General scheme and electrode configuration

In the new Soffron60 analyzer, axial (parallel to the guiding magnetic field) component of electron energy is measured with electric cut-off method characterized by high resolution and reliability and allowing data cross-checking. Electron-optics scheme of the apparatus is presented in Fig. 1. A partial beam is cut at the target of the facility with 1 mm input aperture and directed to the probe (Ref. No. *7* in Fig. 1) inside a system of retarding electrodes. To these electrodes, a pulse of negative potential $-U_{\mathrm{ret}}(t)$ is applied. Electrons reach the probe only if their axial energy eU_0 (in eV) exceeds absolute value of varied retarding potential. Comparison of retarding potential and a probe current I_{pass} pulses gives sufficient information for reconstruction of axial energy distribution in the partial beam, if its current at the input is constant during the measurement. Otherwise, the input current I_{in} and/or current of electrons reflected from the negative potential I_{refl} are to be determined also. For this purpose, special two additional current probes (Ref. Nos. 2 and 3 in Fig. 1) are introduced in the scheme, protected from electrically induced signals with mesh shields 4 and 6. The assembly comprised of the target and all analyzer electrodes can be displaced in two transverse directions, thus allowing scanning of the input aperture over the beam cross-section.

For realization of electric cut-off method, application of a large electric potential is necessary, which makes electric strength the key problem, especially in the presence of the dense high-power beam. Special configuration of electrodes was designed to reduce energy loads at electrode surfaces and to suppress the discharge phenomena. The input aperture 1 mm in diameter not only allows to measure parameters of the beam at a local position, but also serves to reduce current density – due to transverse velocities of electrons, the beam cross-section substantially expands in the analyzer soon after the pin-hole. Mesh electrodes are placed in the areas with weak electric field to avoid problems with expansion of plasma and secondary particle flows as well as mesh sparking in strong pulsed fields. High-voltage gaps are 20–30 mm wide. Near the system axis, where the most part of the studied beam propagates, the electric potential varies with approximately constant rate over ~12 cm length (Fig. 2), thus peak electric field strength is minimized. To reduce secondary emission effects, all apertures have conical shapes with sharp edges.

Besides the axial energy distribution measured during a single facility pulse, the new analyzer may be used to define the transverse component of electron energy, even though it requires a series of shots. The special data-processing techniques are discussed in the next section. To implement this function, the analyzer is equipped with built-in coils for magnetic field distribution control in the analyzer volume (see $B(z)$ plots in Fig. 1). This field does not penetrate upstream from the target, thus disturbance of either the whole facility beam or target conditions is practically excluded.

3. Data processing: approach and technique

Soffron60 measurement data (Fig. 3a) have initial form of 5 oscillograms: 2 voltage pulses (facility gun cathode potential U_0 and the voltage applied to the retarding electrode U_{ret}) and 3 analyzer collector currents (I_{in}, I_{pass} and I_{refl}, see Fig. 1). In the absence of discharges and other parasitic phenomena, we can expect these current waveforms to be in agreement:

$$I_{\mathrm{in}}(t) = a_1 I_{\mathrm{pass}}(t) + a_2 I_{\mathrm{refl}}(t), \quad (1)$$

where constants a_1 and a_2 account for non-equivalent collector properties, such as geometric areas, grid transparencies, etc.

Considered jointly with the potentials waveforms, the collector currents may be used to calculate normalized integral energy distribution (also known as "cut-off function") $S(u)$ defined as relative number of

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