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METHODS AND SYSTEMS FOR DIAGNOSTICS OF ELECTRON BEAMS BY SYNCHROTRON INFRARED RADIATION

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1. INTRODUCTION

One of the most effective methods of the electron ring observing in the ERA compressor without its destruction is this one with the use of synchrotron radiation (SR) of electrons. In this paper, the results of infrared synchrotron radiation using ($\Delta\lambda \simeq 0.3\div45$ µkm) for the diagnostics of the compressed in the ERA electron ring of charged particles are given.

2. PARAMETERS OF THE ELECTRON RING

Taking into account the parameters of the collective accelerator, the spectrum of electrons in the ERA compressor for the most part is in the infrared region (IR) of optical spectra $\Delta\lambda \simeq 1$—100 µm and $\lambda_m > 1$ µm (Fig.1). That is why the methods and diagnostic systems by SR were based on the best apparatus of IR technique (optical materials, radiation detectors).

There were elaborated some methods of measuring the following parameters and charged-particle electron ring characteristics on the last phase of its compression in the ERA compressor (equilibrium radius ~ 6—3 cm):

— electrons number in the ring — Ne;

— equilibrium radius R and small cross-section dimensions a_Z, a_R;

— $R(t)$ — trajectories and dynamics of compression;

— angle divergence of electrons *SR* in the ring.

3. METHODS

Basing on these methods there were elaborated measurement systems for the diagnostics of current and geometrical ring parameters [1,2].

3.1. *Number of Electrons.* The electron number measurement method is based on the direct dependence of SR intensity on the electrons number and the SR registration is made in the spectral region $\lambda \gtrsim \lambda_c$, when the radiation intensity is independent of the electron energy [3]. There are two variants of SR intensity measurement: the approximate one [4] when the radiation is measured only in the median plane by the detector, and the more precise one [5] when the detectors system controls the solid angle, where the most part of the SR is concentrated. The first method is good by simplicity of the apparatus and bad by the absence of

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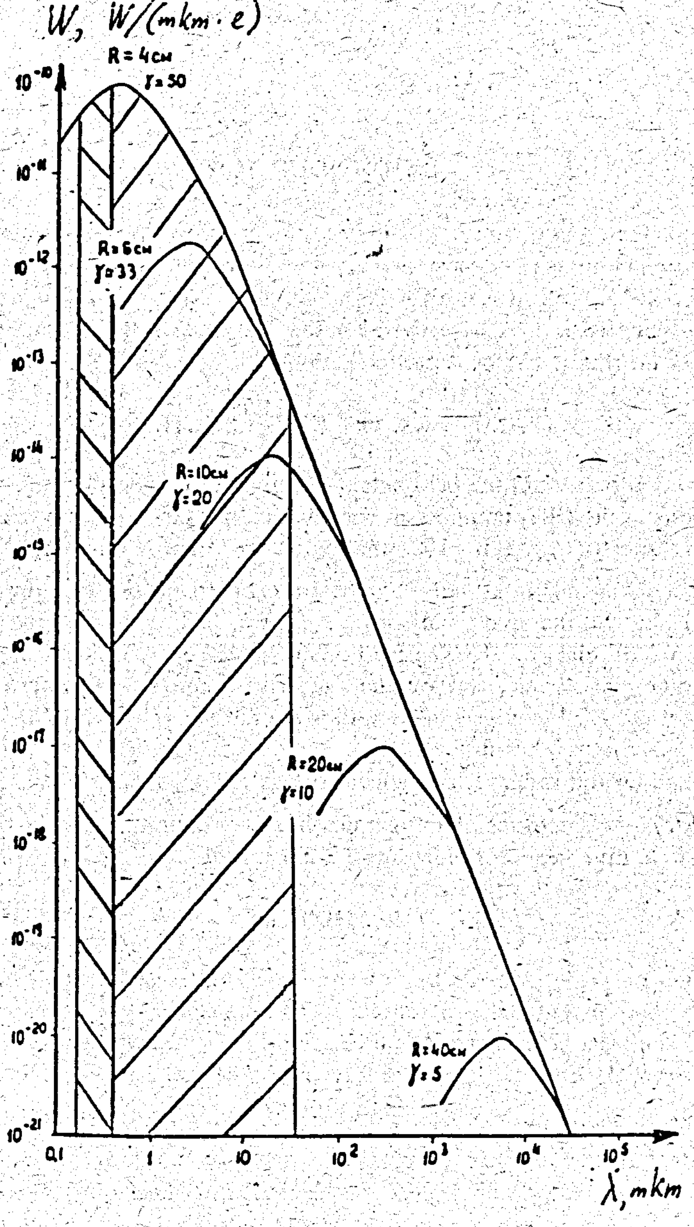

Fig.1. Spectral distributions of the synchrotron radiation from ERA electron ring and radiation region used for diagnostics

operative, for every accelerator pulse, information about the SR angular distribution.

3.2. *Geometric Characteristics.* The ring geometric parameters method consists of the following: the image of small ring coagulate cross-section, being, in the field of view of 2m IR optical channel [6], is focused on the sensitive surface of the detector with linear elements displacing and is registrated by the channel.

3.3. *Angular Divergence.* The important element in the electron-ring diagnostics in the compressor is the angular divergence of SR in the direction perpendicular to the median ring plane. Its measurement permits not only to determine the SR intensity with a high accuracy, but also gives the information about the electron energy and the SR angular distribution (axial betatron oscillation). The base of the method is the registration of SR at the output of the chamber with the help of the multielement IR detector, which length overlaps the most of SR flow in the direction perpendicular to the plane of particle direction.

4. EXPERIMENTAL APPARATUS AND RESULTS

4.1. *Instruments.* The electron-ring diagnostics process includes the following operations: the SR taking out from the vacuum chamber through special high-vacuum window [7], for the SR wave lengths $\Delta\lambda \simeq 1$—8 μm; SR transport with minimal losses with the help of 2-meter optical track and its transferring to the detector; multiple for one acceleration cycle registration of the radiation by the detecting blocks — measurement transformer of SR intensity to the electric signal; isolation of useful signal on the background of pulse electromagnetic interferencies of the amplifier, its amplifying and transport to the electron registration blocks and information storage; measument results processing and the results receiving.

The scheme explaining the geometry of SR and its registration is given in Fig.2 (see also Fig.3).

The ring diagnostics in the compressor was made simultaneously by a few detectors. The compressor block scheme and diagnostic systems are given in Fig.3: 1 — vacuum chamber electron ring

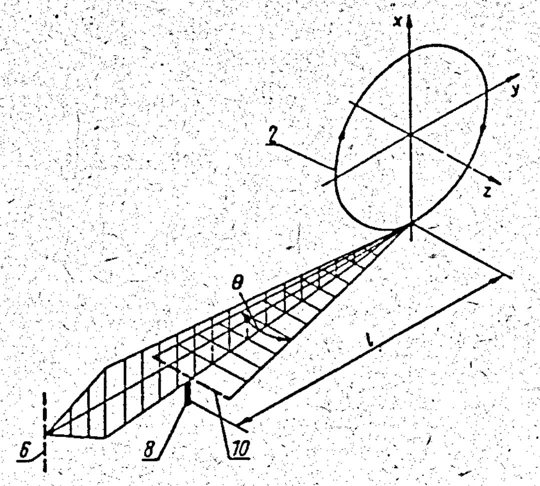

Fig.2. Geometry of synchrotron radiation and its registration

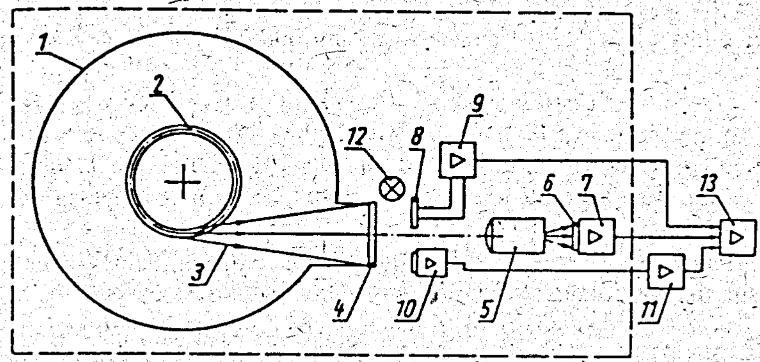

Fig.3. Block-scheme of diagnostic systems

compressor; 2 — electron (electron-ion) ring; 3 — SR; 4 — window; 5 — optical track; 6 — detector for the ring geometrical parameters measurement; 7,8,11 — amplifiers; 8 — one-element IR detector in the median plane of the ring coagulate; 10 — multielement IR detector with preamplifiers block, measuring the angular divergence of IR; 12 — control source (light-diode AL 107 b); 13 — block of electronics and computer.

4.2. *Measuring the Number of Electrons*. The electrons number in the Ne ring can be calculated if one-electron SR power w_1 is known and SR total power W:

$$N_e = \frac{W}{w_1} \qquad (1)$$

is measured. The total SR power can be determined if we know: the coefficient of SR flow using, from Ω-geometrical factor determined by solid angle of SR detector; the coefficient of spectral passing $\tau(\lambda)$ of interval environment (window, filters, optics) and the SR polarization properties; relative spectral characteristic $\varepsilon(\lambda)$ of the receiver.

In general case the signal on the radiation receiver can be the following:

$$U_{SR} = N_e S \, \Omega \int_0^\infty w_1(\lambda)\, \varepsilon(\lambda)\, \tau(\lambda) d\lambda, \qquad (2)$$

where S is the calibration constant of the receiver (V/W) measured with the help of the known methods [8] at the tungsten source.

The synchrotron radiation intensity registration is made in the median plane of the electron-ring one-element infrared detectors: silicon photodiode (0.3÷1.1 μm), selenid plumbum photoresistor (0.7÷4.6 μm), InSb-photoresistor (0.7÷7 μm, 77K), GeAu-photoresistor (1.8÷8.6 μm, 77K) $LiNbO_3$-piroelectric (1÷45 μm).

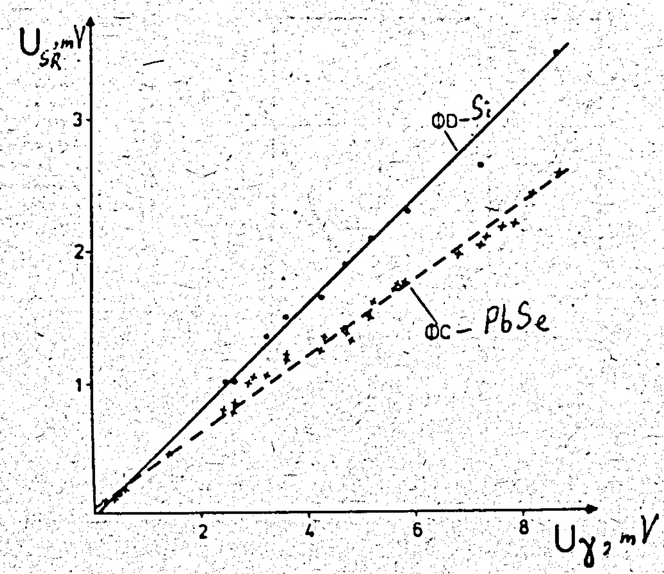

Fig.4. Signal correlation U_{SR} and U_γ

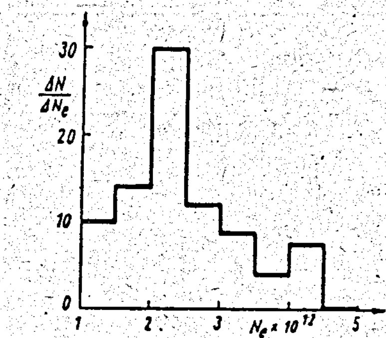

Fig.5. Electrons number in the ERA compressor

To verify the linear dependencies between intensity of registered SR and the number of electrons in the ring, there was examined the correlation of the receiver, registering the SR signals in different spectal regions (silicon photodiode SP, selened plumbum photoresistor PR), and of the detector, registering γ-radiation created when the electrons resat on the wall of the chamber at the end of the accelerator cycly, the intensity of braking radiation was proportional to the electron number.

The made investigations have shown the SR receiver and detector signal linear correlation U_{SR} and γ-quanta U_γ. The investigation results are shown in Fig.4. The electrons number measurement results during one of KUTI-20 experiments are given in Fig.5.

4.3. *Equilibrium Radius and Small Cross-Section*. Ring geometrical parameters in the compressor were measured by two detecting systems. At the prototype of collective accelerator (PKUTI) the measurements were made by the system with 50-element photoregister made of photoresistors InSb [9] cooled by

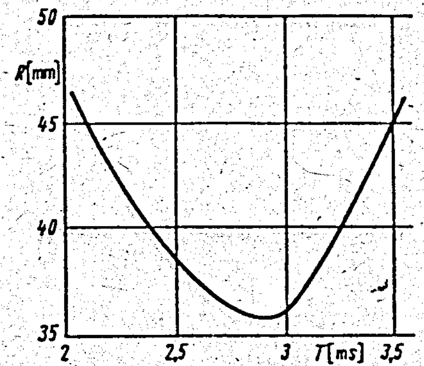

Fig.6. $R(t)$-trajectory

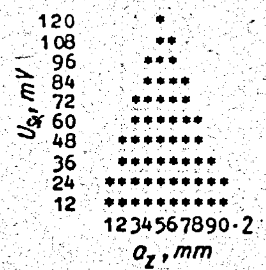

Fig.7. Cross-section of the electron ring

the liquid nitrogen. At the KUTI-20, the system with 10-element detector made of plumbum selenid [10] was used. Both of them are one-coordinate systems which permit one to measure the small cross-section dimension of the ring, parallelly to the median ring plane (a_R), or perpendicularly (a_Z). Systems operating is illustrated in Figs.6 and 7. In Fig.6 the ring $R(t)$ trajectory measured for one of the acceleration regimes is shown. In Fig.7 the instant dimension of small cross-section of the ring is given.

4.4 *Results of Measuring the Angular Divergence of Synchrotron Radiation.* Angular SR distribution measurement for one-element detector meter of electrons number was made simultaneously by two photoreceiver: the silicon one, moving perpendicularly to the orbit surface and the pulse one of PbSe, placed at a zero angle to the orbit plane. The angular SR distribution for a large interval of wavelengths ($\Delta\lambda \simeq 1$ μm) was calculated by the average multi-pulses value [11].

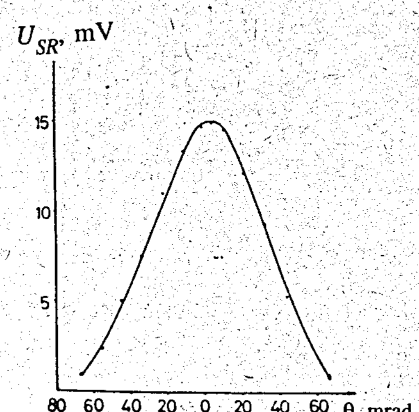

Fig.8. Angular synchrotron radiation distribution measurement results for one-element IR detector

The one-channel system measurement of angular divergence of synchrotron radiation is illustrates in Fig.8.

The multi-channel system for measuring the synchrotron radiation power and the angular distribution on compressor is described in Ref.[5]. The system allows one to register radiation in 0.7÷4.6 μm spectral region in ten time-moments during 1 ms, when the electron ring compresses from 5.2 to 3.8 cm radius. The detector consists of 30 uncooled photoresistors made of PbSe, 0.2x4 mm in size, with 120 mm long linear arrangement of elements.

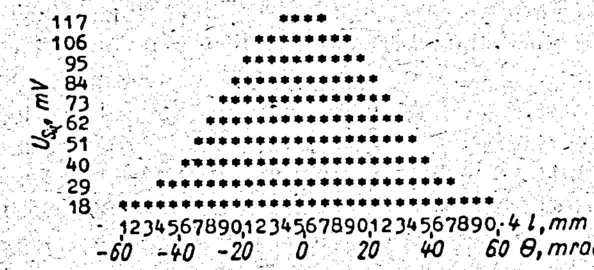

Fig.9. Angular distribution, measured in one of 10 moments of ring compression

The multichannel system measurement of angular divergence of SR is illustrated in Fig.9. There is shown the instant value of the SR angular distribution, measured in one of 10 moments of ring compression. The vertical axis gives us the amplitudes of signals from every detector element, the horizontal — the element number (the line step — 4 mm) and the angle relatively to the median ring plane. The system permits one to observe the compression dynamics at energy accelerating cycle. Semi-widthness of the distribution is determined by the energy of electrons in the ring and their betatron oscillations.

5. CONCLUSION

Methods for measuring current and geometric parameters and for estimating ring energy parameters in compressor-ring using synchrotron radiation of visible and infrared range ($\Delta\lambda = 0.3 \div 45$ μm) are presented as well as information about measuring system created on its base. Spectrum of synchronous radiation is mainly in infrared range (wave length range is > 1÷100 μm). Elements of infrared optics are used — high vacuum window made of MgF_2 (analoge IRTRAN-1) and 2m mirror optical channel. Radiation is registered by cooled and operating at room temperature infrared detectors prepared from Si, PbSe, InSb, GeAu, $LiNbO_3$. Results of measuring the number of electrons in a ring, equilibrium radius and dimensions of small cross-section of ring bunch, angular divergence of synchrotronous radiation, relatively to ring median plane, are presented.

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