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ALTERATION OF THE ION BEAM EMITTANCE ON THE FIRST ORBITS IN THE CYCLOTRON

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Abstract.- Ion beam emittance and other beam characteristics measurements have been performed in the central region of the compact, large magnet gap cyclotron with full scale ion source at the Alma-Ata cyclotron facility, beginning from the very first orbits. The features of the mechanical slits transfering system and digital beam intensity measuring system are presented and the obtained results are discussed.

1. Introduction.- The efficiency of the ion beam acceleration in the cyclotron in essential extent is determined by the emittance of the beam which is extracted from the ion source. It is in the centre of the cyclotron that ions get practically preserved amplitudes of the radial and axial oscillations. In this connection knowledge of the real initial distribution of current density of the beam in phase space volume is the necessary condition both in solving the problem of its accordance to the accelerator admittance and in the investigation of further beam dynamics and improvement of the beam extraction efficiency.

Up to this time great deal of investigation concerning the cyclotron central region was carried out[1,2]. However the main part of this investigation concerns only the ion source itself. At the same time the investigation of ion beam emittance at real cyclotron conditions and its evolution at the initial orbits are of great interest. This report presents briefly a description of the central region testing facility and the results of ion beam characteristics measurements[3].

2. Experiments.- The cyclotron magnetic field is excited by two windings which are fixed to the C - type magnet. The pole diameter is 500 mm and the magnet gap is 200 mm. Application of stabilized direct current sources for feeding the magnet windings provides the magnetic field induction in the range of 4 kG - 12 kG with accuracy of $2 \cdot 10^{-5}$. The dee aperture is 40 mm and dee position can be adjusted vertically. Accelerating high frequency electric field is excited by a single dee resonant line. This system is a quarter-wave coaxial resonator which is fed by a high frequency oscillator with symmetric output. The frequency range of the oscillator is 3 MHz - 22 MHz, the power is 25 kWt. The installation performs both at the pulse mode, duty factor being 2 - 100, and also at continuous mode. The vacuum chamber construction provides easy access to the cyclotron central region. Figure 1 shows the vacuum chamber with dee, ion source and two probes installed.

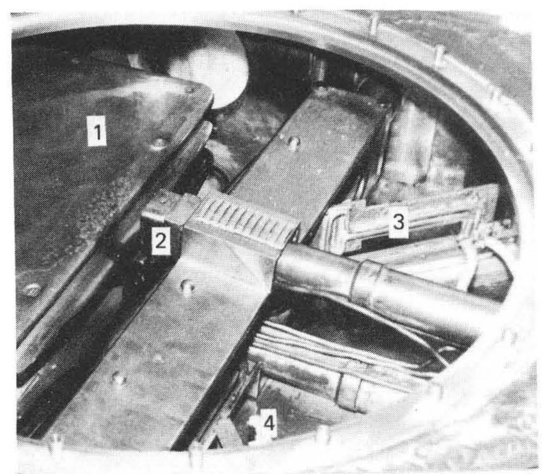

Fig. 1. The cyclotron vacuum chamber.
1-dee, 2-ion source, 3-first probe, 4-second probe.

Beam emittance measurements are carried out with the aid of two probes, the first one is located at the 45 degrees position and the second one at the 135 degrees position respectively. The probes can be moved remotely over a radial range of 40 mm - 180 mm with 0,1 mm accuracy. Figure 2 shows the location of the probes in the cyclotron central region, the dashed line shows ion trajectory.

Two probes are used to measure the radial beam emittance. The first probe carries a diaphragm with 1 mm vertical slit. The diaphragm is made of tantalum and is clamped to a water-cooled copper plate. Graphite sheets are located in front of the diaphragm to

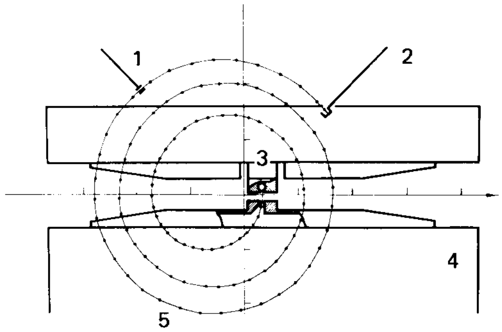

Fig. 2. Central region geometry.

1-slit diaphragm probe, 2-current probe, 3-ion source, 4-dee, 5-ion trajectory.

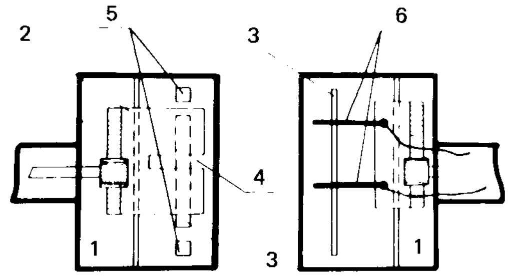

Fig. 3. Diaphragm and current probes.

1-radially movable plate, 2-axially movable plate, 3-axial slit, 4-radial slit, 5-axially unmovable openings, 6-current electrodes.

prevent it from the excessive heating. The first probe is also used as an integral current probe. The current value and the width of the beam that comes through the first probe slit are measured by the current electrode which is clamped to the second probe. The current electrode is a vertically placed 1 mm diameter tungsten wire.

Two probes are used to measure the axial beam emittance. A tantalum diaphragm is mounted on the first probe. The diaphragm consists of two parts. One of them with two symmetrically located 1 mm slits at the distance of 22 mm from the median plane is mounted to the probe in a fixed position. The second part with 1 mm horizontal slit can be vertically moved over 22 mm range with 0,1mm accuracy. Such kind of diaphragm has provided cutting out the beam by the slit over the full dee aperture. The current value and the height of the beam that comes through the first probe slits are measured by two identical current electrodes. The vertical distance between them is 20 mm. The current electrodes are horizontally placed 1 mm diameter tungsten wires. They are located on the second probe and are remotely adjusted in vertical direction over 22 mm range with 0,1 mm accuracy. This provides the measuring of the beam current over the full dee aperture.

The described system was used for preliminary emittance measurements. During the final measurements the first probe slits were replaced by the rectangular opening 1 mm x 1 mm. It was formed by the two 1 mm slits which were independently movable in radial and axial directions. Such diaphragm is fit for beam emittance measurements both for radial and axial planes. At the second probe a sheet with 1 mm vertical slit was placed in front of the horizontally located current electrodes. This system is shown in figure 3.

Figure 4 shows the block diagram of the beam current measuring equipment. The part of the beam (13) that comes through the

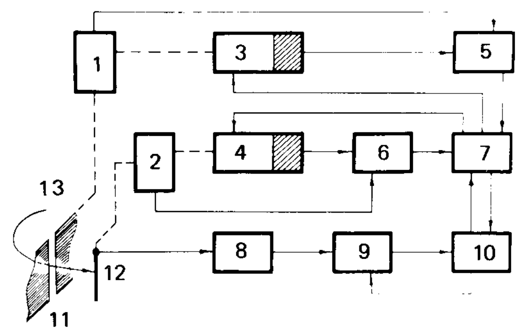

Fig. 4. Block diagram of the beam current measuring equipment.

1,2-linear movement pickups, 3,4-electromechanical probes with schemes for detection of the drive angular position, 5,6-coincidence circuits, 7-block of the programmed control, 8-low frequency filter, 9-analog-to-digital converter, 10-multi-channel pulse-height analyser, 11-slit diaphragm, 12-current electrode, 13-ion beam.

first probe slit (11) falls on the second probe current electrode (12) and then via low frequency filter (8) is applied to the analog-to-digital converter (9), after which the pulses are fed to the input of the multi-channel pulse-height analyser (10). The analyser is operating in the mode of slow time analysis. Storage of information takes place in the memory of the analyser. Pulses, which are switching the channels of the analyser, control the operation of the analog-to-digital converter. An optical system of starting pulses formation is used for synchronization of the digital measuring system. The optical system consists in the block of the programmed control (7), the coincidence circuits (5,6), the linear movement pickups (1,2) and electromechanical probes with schemes for detection of the drive angular position (3,4). The block of the programmed control provides synchronous shift of the slit (11) per the discrete distance along the radius beginning with the first orbit. At the each position of the slit an scanning of the beam by the current electrode (12) takes place. The beam current signals are applied to the input of the multi-channel analyser, which operates in one of the subgroups. Each subgroup contains 64 channels, the switching of the channels is provided by the block of programmed control. The results of measurements, which are stored in the digital form, provide the possibility of efficient investigation of the cyclotron ion beam emittance with the aid of a display or a plotting device.

Before the measurements were carried out preliminary calculations have been made to choose the dimentions of the diaphragms, current electrodes, range and step of their radial and axial movement. Final treatment and analysis of the experimental data have been made with the aid of a mathematical model, which was fulfilled in FORTRAN language. The investigated trajectories were defined by numerical integration of ion movement equations taking into consideration space distribution of the magnetic and electric fields. At these calculations the electric field was considered as a time function.

3. Results and conclusion.- Results of the radial and axial phase space density measurements for the initial three orbits have been obtained. Figures 5 and 6 show typical distribution of the beam current density at the first orbit for radial and axial directions respectively. These measurements were carried out at the following cyclotron operating parameters: main magnetic field was 7,3 kG, accelerating electric field frequency was 11,2 MHz, dee voltage amplitude ~70 kV. The value of the dee voltage amplitude was calculated taking into account the measured values of the turn separation between initial orbits. The outer lines of the phase space figures are the total beam current emittance areas. The inner lines are density contours for 80 %, 60 %, 40 % and 20 % of the beam current. The measured values of the beam emittance for 80 % current density at the first orbit are 420 π mm mrad for radial direction and 320 π mm mrad for axial direction. Beam emittance for the second and third orbits show small changing of the current density distribution.

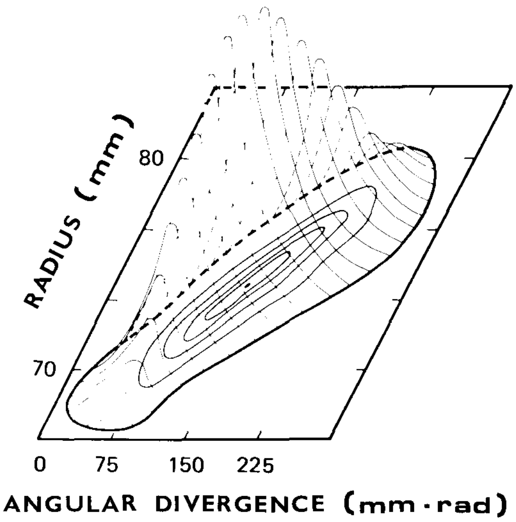

Fig. 5. Beam emittance and current density distribution in the radial phase plane.

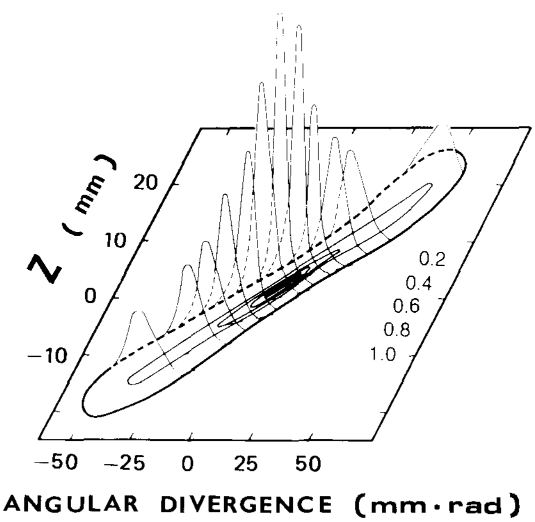

Fig. 6. Beam emittance and current density distribution in the axial phase plane.

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