STUDY OF BEAM PARAMETERS OF 240-CM ISOCHRONOUS CYCLOTRON

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Abstract

For two years beam parameter investigations have been carried out at the Kiev cyclotron for the extraction process and the beam transport system. The data obtained show that high quality beam is obtained with 0.1% accelerating voltage stabilization and shape selection of the isochronous magnetic field which limits phase shift to ±5°. The system for radial beam phase selection provides control of bunch phase duration within 5°-25°. In this case the radial oscillation amplitude does not exceed 2-3 mm and extraction efficiency from the cyclotron is about 70%. The measured beam emittance at the accelerator output is 20 mm-mrad. for vertical motion and 28 mm-mrad. for horizontal motion. Energy spread in the extracted beam is less than the energy gain per turn and is about 0.3%. The complete beam transport system is in use and provides beam without losses to any of six experimental rooms.

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In March 1976 on the 240-cm isochronous cyclotron an accelerated proton beam with a final energy of about 53 MeV was first obtained, and in December the beam was extracted out of the cyclotron chamber. Research work conducted on the cyclotron for over two years developed in two directions: generation of beams with different final energies, and study of internal and external beam characteristics. In 1976 proton beams were accelerated up to energies of 53 and 72 MeV, deuteron beams up to 26, 50 and 64 MeV, $^4He^{+2}$ ion beams up to 52, 105 and 130 MeV.

Proton beam parameters in acceleration modes up to 53 and 72 MeV are studied in detail. The realization of a "constant orbit" principle both in the initial acceleration zone and in the beam extraction region allows an extension of this data to the whole range of accelerated particle energies and types. The arrangement of central optics and beam extraction system elements, selected for the acceleration mode of protons up to 53 MeV, remained unchanged for other energies. Experimental results confirm reproducibility of beam parameters in changing the energy, if conditions of "orbit constancy" are met.

Numerical simulation of the acceleration process, taking into account real values of the beam transverse and longitudinal emittance and the discrepancy between this emittance and the cyclotron acceptance, made it possible to formulate requirements on the beam phase selection and to predict parameters of radial and longitudinal motions. This data was experimentally confirmed with a good accuracy. As an example Fig. 1 gives the dependence of beam current density measured by a probe differential tip of 1 mm width on the radius of the first six turns. Density peaks, corresponding to individual turns are in agreement with estimated values with an accuracy of better than 1 mm. Their widths are also in good agreement with estimated values.

The 240-cm isochronous cyclotron employs a radial phase selection system, comprising two one-flap collimators. The location of collimators on different azimuths provides an effective beam selection. Fig. 1b shows the same dependence as in Fig. 1a, obtained after mounting the collimators. The efficiency of using radial phase selection is defined by two factors. First, the dee voltage should be set to the desired position with an accuracy of 0.5% and its value should be stabilized at a level of 0.1-0.3%. Second, an injected beam should be of high quality. The second requirement is connected with optimization of the ion source and with selection of its extracting slit size.

With a 2 x 10 mm slit source at the cyclotron, phase extension of the current pulse was regulated in the range of 15-20°, and an amplitude of radial oscillations was 4-5 mm. A decrease in the source slit width to 1 mm led to a marked increase in selection accuracy. The beam phase length was regulated within 5-25°, and an amplitude of radial oscillations for different values of the beam phase band was between 2 and 4 mm.

Small coherent oscillations (3-5 mm) in the beam do not worsen its quality if an isochronous magnetic field is properly achieved (phase motion due to non-isochronism is not over 5-10%). Otherwise mixing of coherent oscillations into incoherent ones takes place, and the beam quality greatly worsens. This effect -- illustrated by data of Fig. 2a -- corresponds to isochronous acceleration. In non-isochronous acceleration (Fig. 2b) mixing of oscillation occurs, and the amplitude of incoherent oscillations is about 8 mm at the end of acceleration.

The efficiency of beam extraction from the Y-240 cyclotron is mainly determined by capturing the beam at the deflector and transmitting the beam through it, because all the subsequent extraction elements (current channel, magnetic shield and correcting electromagnet) have larger apertures.

The beam is extracted from the magnetic fringe field region (extraction radius is 103 mm), where the radial oscillation frequency is about 0.9. Therefore, the beam extraction efficiency is low (about 10%), if external magnetic windings are not switched on. In optimization of the amplitude and first harmonic phase the efficiency of the beam passing through the deflector reaches 70%. The extraction efficiency strongly depends on magnetic field tuning and beam quality at the deflector entry, respectively. Fig. 3 gives resonance curves, corresponding to the final radius of deflection. An unusual shape of the resonance curve $I(\delta B)$ after the deflector is due to the fact that the deflector is a collimator with respect to coordinate and angle r, r' and, therefore, for different values of δB allows different transmission of the beam.

When the magnetic field is tuned by the $I(\delta B)$ curve maximum, which corresponds to the curve in Fig. 2a, i.e. the high quality beam, the conditions for capturing the beam by the deflector are optimal, and extraction efficiency is about 70%. With the mistuned magnetic field (flat-top on the resonance curve), extraction efficiency is about 40%. In this case non-isochronous acceleration leads to mixing of coherent radial oscillations into incoherent, and the beam quality markedly worsens.

Fig. 4 gives current density distribution of the beam after the current channel and magnetic shield, corresponding to estimated data for the beam with energy spread of about $3 \cdot 10^{-3}$, i.e. within the energy gain per turn.

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The emittance in the first section of the beam line was measured by a method of slit optics. Radial emittance was about 16 πmm.mrad, and vertical 18 πmm. mrad.

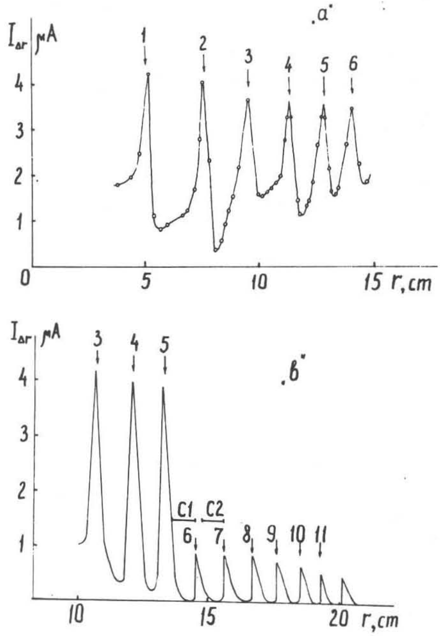

Fig. 1. Dependence of beam current density on radius in the cyclotron central region:
"a" - without collimators;
"b" - with collimators

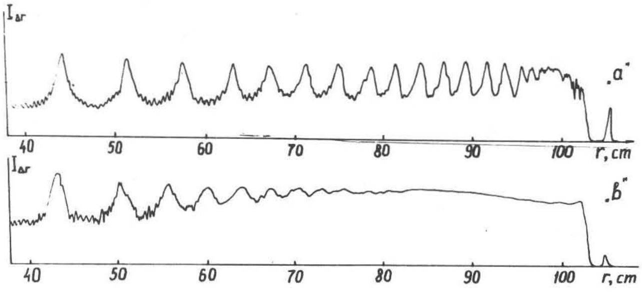

Fig. 2. Dependence of beam current density on radius:
"a" - isochronous acceleration mode;
"b" - non-isochronous acceleration mode

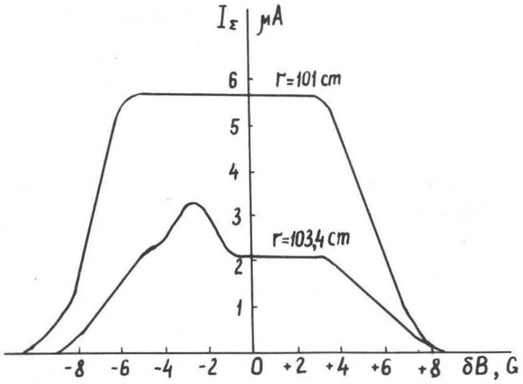

Fig. 3. Resonance curves
Γ = 101 cm is the finite radius of acceleration; Γ = 103,4 cm is the acceleration radius after the deflector

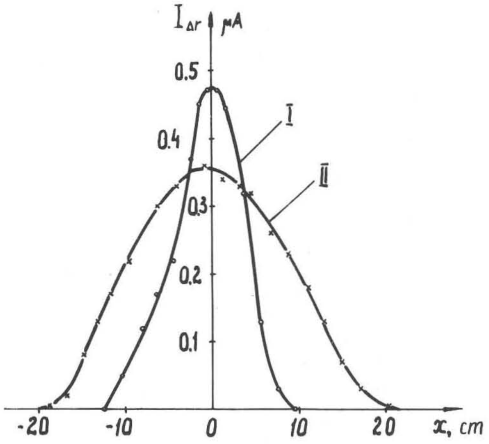

Fig. 4. Distribution of beam current density after the current channel (curve 1) and magnetic channel (curve II)

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