BEAM EXTRACTION SYSTEM IN THE KIEV 240-CM ISOCHRONOUS CYCLOTRON

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Abstract

Experimental characteristics of a compensated current channel, an iron magnetic screen and an alignment magnet, forming a part of the Kiev 240-cm isochronous cyclotron beam extraction system, are given. The current channel, at supply power of 80 kV, provides reduction of the magnetic field level by 2 400 G and a positive radial field gradient up to 200 G/cm. The magnetic screen, reducing the field by approx. 400 G, also focuses the beam in the horizontal plane. The field focusing gradient depends on the external field level approximately linearly and reaches 400 G/cm. The alignment magnet has dipole and quadrupole windings, producing a magnetic field up to 4 000 G and a gradient up to 300 G/cm. Magnetic field perturbations, introduced by the extraction system elements in the beam acceleration region, do not exceed 10 G in the first harmonic.

Introduction

In the 240-cm isochronous cyclotron, the average magnetic field level on an extraction radius ranges from 5 000 G to 17 000 G for various acceleration regimes. Maximum energies of protons, deuterons and heavy ions are 100 MeV, 70 MeV and 140 Z^2/A MeV, respectively. The ions are initially deflected with a short 30° deflector. At the electric field strength of 120 kV/cm, orbit separation following the deflector is 1.3 cm. Matching the ion beam trajectory to the beam transport system axis, as well as beam emittance and first quadrupole acceptance matching, is accomplished with the compensated current channel, iron screen and alignment magnet.

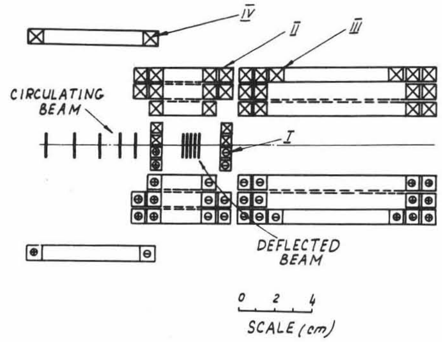

Fig. 1

Current channel winding configuration

I	septum winding
II	field winding
III	compensating winding
IV	correction winding

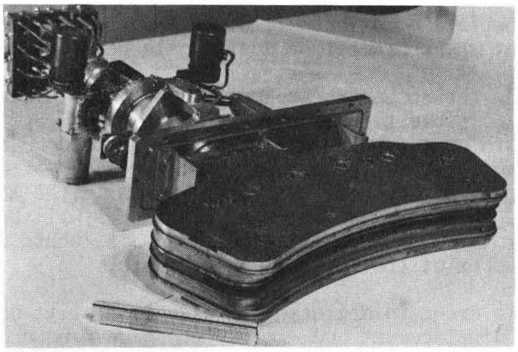

Fig. 2

Compensated current channel

Compensated Current Channel

The choice of a septum type compensated current channel was dictated by the need to reduce the magnetic field by 2 200 - 2 500 G, as well as by small orbit separation after the deflector and a wide range of the magnetic field change in the region of channel position (from 7 000 G to 20 000 G). A conductor arrangement was chosen from calculations and tests of a channel full-size model. The current channel design model is given in Fig. 1. Indicated on it are: "septum", "field" and "compensating" sections of windings, fed in series from a 50 V/1600 A source, and a "correction" winding fed from a 10 V/2400 A independent source. Current instability is no more than 3 x 10^{-4} and 10^{-3}, respectively. All the windings, except the septum, are made of 8 x 8 mm copper with a 5 x 5 mm slot for cooling water. The septum winding is of 6 x 6 mm copper with a 3 x 3 mm slot. In further manufacturing of the current channel, the configuration of windings was slightly modified. Fig. 2 shows the compensated channel external view. Required mechanical strength and close tolerances on winding location are achieved by locating the winding sections in grooves of separate blocks and sealing them with epoxy compound. The blocks are welded into a monolithic container. At supply current of 1600 A, the power consumed by the channel windings is 80 kW. Inlet pressure of cooling water is 15 kg/cm^2 with eight parallel water branches. The septum

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thickness at the channel entrance is 1.0 cm, and beam aperture is 1.8 x 2.1 cm (wide and high). The channel position is remotely controlled. The distribution of the channel magnetic field over its transverse and longitudinal axes is shown in Fig. 3a and Fig. 3b.

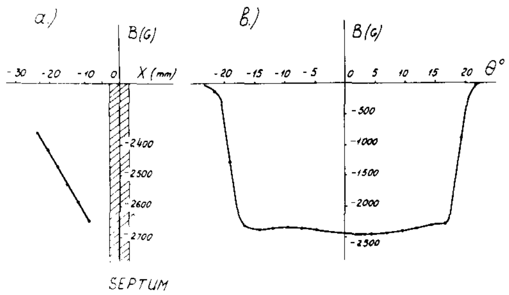

Fig. 3

Magnetic field distribution of current channel along

a) transverse and
b) longitudinal axes

On the average, over the channel length of 66 cm (38°), the field reduction achieved is 2 400 G while the radial gradient is about 200 G/cm. In operation regime at I = 1600 A, the first harmonic amplitude of magnetic field perturbation does not exceed 5 G in the beam acceleration region and, therefore, can be compensated comparatively easily. Magnetic field perturbations change only slightly with changes of the external field for one value of the channel supply current.

This is seen in Fig. 4, which shows magnetic field perturbations in the acceleration region over the channel transverse axis. Also shown are the channel results (curve I) and channel model results (curves II and III). Measurements of the field distribution in the vertical plane have shown that, within the beam aperture, the distortions of the channel field mid-plane present no danger.

Iron Magnetic Screen

The next element of the beam extraction system is an iron magnetic screen, located in a "valley" between sectors, where the field level ranges from 3 000 G to 8 000 G in most acceleration regimes. Only in heavy ion acceleration regimes, when the extraction radius average field exceeds 15 000 G, does the "valley" field reach 10 000 G. Calculations have shown that, with a screen 25.0 cm long, external field screening should be no less than 0.5, and an effective focusing gradient should be 350 G/cm in the 100 MeV proton extraction regime. The magnetic screen configuration has been chosen from tentative modelling, as well as from magnetic measurements on the cyclotron in January 1975. The measurements were conducted at five levels of the cyclotron field, conforming to acceleration regimes of protons up to 65 MeV. (The field in the cyclotron centre is about 5 000 G, 10 000 G, 11 425 G, 14 260 G and 16 410 G.) The purpose was to provide required parameters of the screen at the largest beam aperture and an approximately linear dependence of the effective gradient on the cyclotron field level. A final version of the screen is given in Fig. 5. It shows "a" a main version (for the field up to 15 000 G), and "b" an additional version (for the field exceeding 15 000 G). The two versions differ from one another by the amount of shear on the edges (40° and 20°, respectively.

For the main version, the screening is no less than 0.5 (4 000 G) at the valley field level of 7 800 G (H_0, the central field, is 14 260 G). The screen of type (b) provides reduction of the field by 5 000 G at a level of 9 500 G (H_0 = 16 410 G).

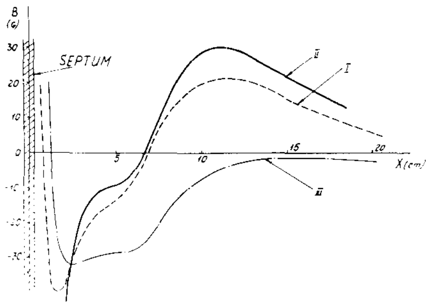

Fig. 4

Magnetic field perturbations in the beam acceleration region (along the channel transverse axis) for the channel (I - in air) and the channel model (II - in air, III - in magnet)

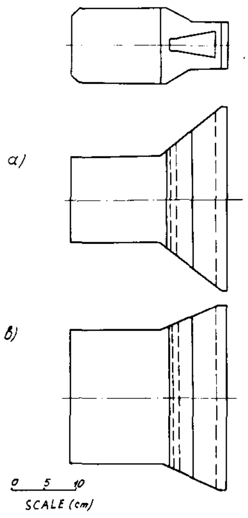

Fig. 5

Magnetic screen

"a" - for H_0 < 15 000 G
"b" - for H_0 > 15 000 G

A positive radial gradient of the field is produced at the cost of shear angles on the screen edges, a variable internal screen aperture and a configuration of the screen iron masses in the immediate vicinity of the beam aperture. Although the contribution of each factor to the effective gradient is dissimilar for different levels of the external magnetic field (this is well seen in Fig. 6, where the gradient distribution over the screen length for H_0 = 5 000 G, 11 425 G and 14 260 G is shown), it was possible to obtain an approximately linear dependence of the effective gradient on the valley field level. Fig. 7 gives the transverse distribution of the effective gradient (at the screen effective length of 26.0 cm) for beam extraction in different regimes. For the "b" screen at H_0 = 16 410 G, the focusing gradient is 500 G/cm. The screen beam aperture is 4.5 cm horizontally and 2.5 cm vertically. Within the 2.5 cm high aperture, the non-linear character of the field distribution is hardly felt. Iron shims (20 x 1.4 cm and Ø 1.6 cm at height of 4.4 and 5.8 cm), spaced at 6.8 and 14.0 cm from the screen and rigidly secured to it, provided the reduction of the magnetic field perturbation level in the acceleration region down to 5 G in the first harmonic for all acceleration regimes.

Alignment Magnet

The alignment magnet is the last element in the beam extraction system. It serves to "join" the extracted beam trajectory with an ion guide axis and to focus the beam in the horizontal plane. The magnet is constructed in the well-known "window-frame" scheme with curving poles. The dipole winding (60 V/1 000 A) produces a field up to 4 000 G, changing the beam exit angle, if necessary. The quadrupole winding (80 V/38 A) makes it possible to realize effective and easily controlled horizontal beam focusing with field gradients up to 300 G/cm. To eliminate fringing field effects of the cyclotron varying for different operation regimes, the electromagnet is enclosed in the screen. The magnet yoke length is 65.0 cm, aperture is 5.0 x 23.0 cm. The cooling water pressure is 20 kg/cm^2. During magnet tests, design characteristics of the magnetic field have been obtained. Steering field inhomogeneity within the aperture occupied by the beam (± 8.0 cm) does not exceed 1 %. Field gradient inhomogeneity in the same region is 2 - 4 % over the magnet length. Within the beam aperture, non-linear distortions of the magnetic field are not observed in the vertical plane. Magnetic axis departure from the magnet geometric axis is 0.03 cm.

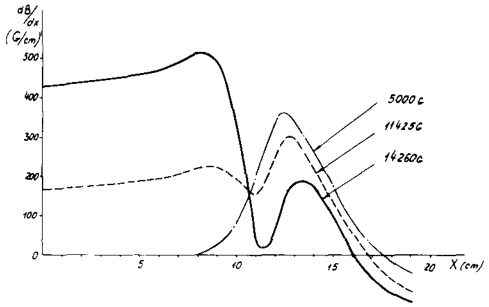

Fig. 6

Focusing gradient distribution along the magnetic screen longitudinal axis

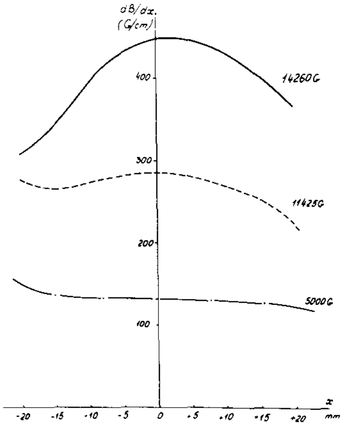

Fig. 7

Effective gradient distribution along the magnetic screen transverse axis