The Axial Injection System of the Isochronous Cyclotron

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Abstract

The design and first experimental results of the axial injection system are described. Two main elements determine the parameters of this system: magnetic focusing elements, which transport ions into the center of cyclotron with an acceptance of 459 π mm·mrad, and spiral inflector. The transmission of a deuteron beam with low emittance including capture into an accelerating process reached 40%.

1 INTRODUCTION

The isochronous cyclotron U-120M has been working in the Nuclear Physics Institute in Řež since 1977. Its basic parameters are: diameter of a magnet poles is 1.2 meters, maximal energy is determined by K=40, range of mass to charge ratio A/Z on the 1st harmonic is between 1–2.8. The diameter of an axial hole through the magnet is 80 mm. The first version of the axial injector was based on electrostatic elements (electrostatic spiral quadrupoles). Due to unsatisfactory optical parameters of these elements [1], we elaborated a new version of this project. This new axial injection system is based on electromagnetic elements, especially on solenoids. The majority of the ion-optical parameters and operational characteristics were tested on an experimental magnet, which is a 1:1 copy of the cyclotron magnet.

2 GENERAL DESCRIPTION OF THE SYSTEM

The project took into account experience of several laboratories [2], [3], [4]. The calculations were realized using both the program TRANSPORT and the relations which appeared in [5]. Influence of a space charge was not included. Fig. 1 depicts components of the axial injection system. The horizontal part starts with radio-frequency ion source (1), which is placed on a potential regulated up to 35 kV. A 5-gap accelerating structure (2) is supplemented with an einzel lens, which has an independent supply. The correction magnet (4) compensates for a stray magnetic field produced by the cyclotron. A diagnostic unit (5) consists of a Faraday cup, exchangeable collimation slits of a circular shape and an illuminated shade. The beam is bent into a vertical beam line by means of a double focusing magnet (6) ($\alpha = 90^\circ$, $\beta = 26.5^\circ$). A classical first harmonic buncher (7) is placed behind this magnet. Then follow: the second correction magnet (8), the second diagnostic unit (10), a vacuum valve and two electromagnetic B-channels (9), (12) which ensure efficient focusing of a beam. The beam is bent into the cyclotron median plane by means of the spiral inflector (13) (Belmont-Pabot type).

2.1 The Vacuum System

The minimal inner cross dimension of the beam lines up to the second B-channel is 50 mm. The pipe through the second B-channel has diameter 37 mm and length 1300 mm. The whole line is connected to a 2000 l/s diffusion pump (3). Vacuum connection to the cyclotron chamber is done via a pipe of a diameter 20 mm. The working pressure measured in the place of the RF ion source is $6 \cdot 10^{-4}$ Pa. At present, a 60 l/s turbo-molecular pump (11) is beeing installed in the place of the vacuum valve.

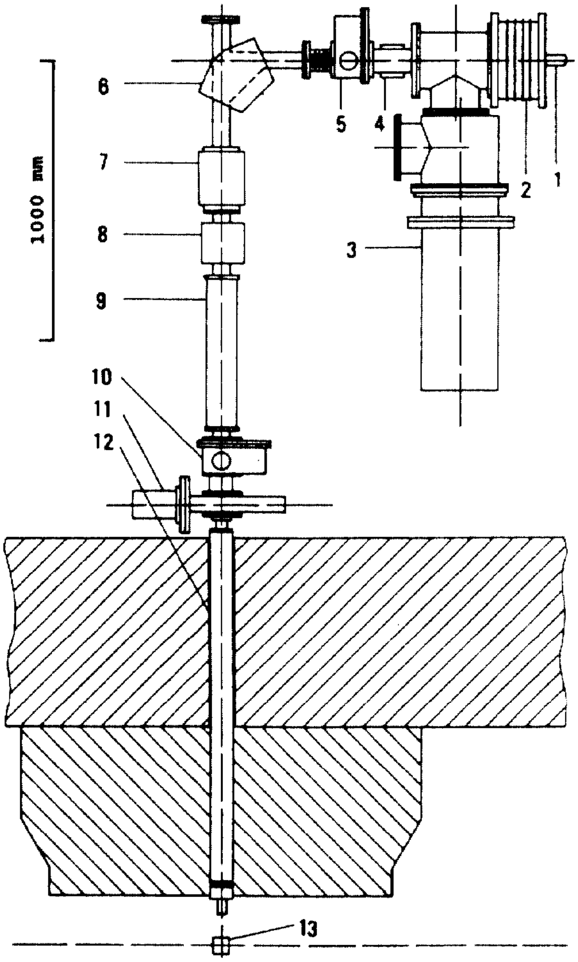

Figure 1. Arrangement of the axial injection system. The description is given in the text.

2.2 *The B-Channels*

The main parts of the vertical beam line are two electromagnetic channels, classical solenoids modified by an appropriate supplementation of the inner magnetic structure (see fig. 2). Combination of the iron (1) and brass (2) rings creates a system of thin magnetic lenses. The coils (4) are cooled by water. The item (3) depicts the vacuum chamber and number (5) is the magnet yoke. This modification of the solenoids essentially improved optical characteristics of the magnetic system and suppressed axial non-symmetry of the magnetic field.

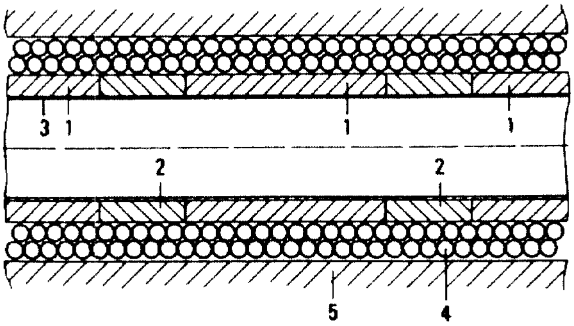

Figure 2. Detailed cross-section of the B-channel.

An axial magnetic field along the axis of the second B-channel for the focusing of 17 keV deuterons is shown in fig. 3.

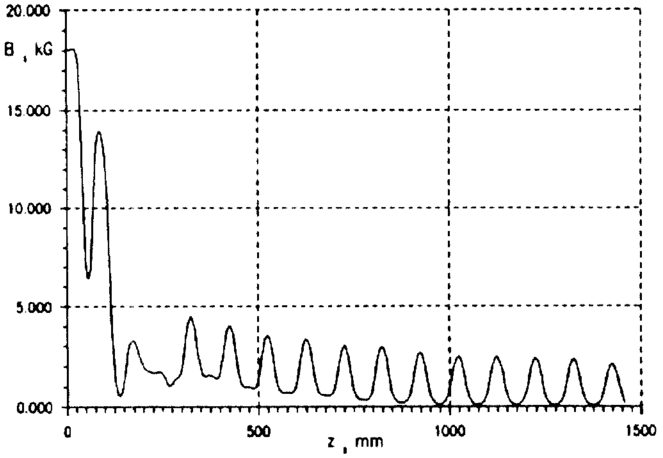

Figure 3. Magnetic field along the cyclotron axial hole with the B-channel.

2.3 *The Inflector*

The spiral inflector of Belmont-Pabot type with unslanted electrodes was chosen for bending the beam into the central plane of a cyclotron. Arrangement of the central region is shown in fig. 4. Electric and magnetic radii of a central trajectory are 26 mm and 14.6 mm respectively, the gap between electrodes (1) is 8 mm and the entrance slit (2) has a diameter 7 mm. The electrodes are supplied with two independent power supply up to 10 kV. This enables us to correct a vertical beam position in the central plane. An electric shielding together with an output channel (3) protects the spiral electrodes against a disturbing HF voltage of the dee (5). The inflector electrodes are cooled only by a heat-transfer into a supporting construction.

Possibility of a simple exchange with the radial ion source was one of the most important requirements for the construction. There is approximately a 4 mm parallel shift of a new puller (4) slit in comparison with the original arrangement. There originates an uncentering of the beam in this arrangement. This is compensated by harmonic coils which correct the position of the magnetic center.

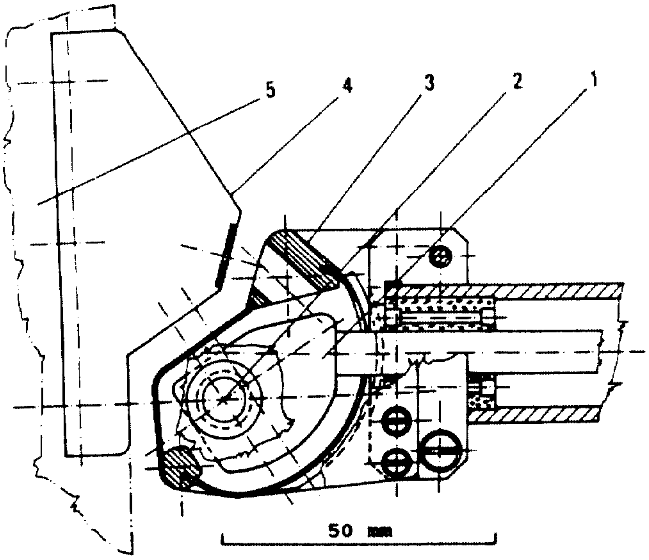

Figure 4. Central region geometry of the cyclotron U-120M.

3 THE EXPERIMENTS ON EXPERIMENTAL MAGNET

All characteristics of this system were tested on an experimental magnet without stopping the cyclotron operation. The acceptance and transfer coefficient in different parts of the injector were tested for protons and deuterons of an energy range 10–35 keV and currents up to 50 μA. Both characteristics were measured for the transport of the beam from the beginning of the vertical line to the Faraday cup in the cyclotron center. The transfer coefficient of the beam with normalized emittance of 0.29 π mm·mrad reaches 80–100 %.

4 THE EXPERIMENTS ON CYCLOTRON

For the first testing experiment we chose the D^+ regime of energy 20 MeV, which is close to the regime with heavy ions. The corresponding injection energy of deuterons was 17 keV and the potentials of the inflector electrodes were +5.4 kV and -4.0 kV. During the experiment, we increased the capture of particles into the accelerating process by the regulation of the central magnetic plane in the cyclotron center. There are shown transmission coefficients in different parts of the vertical line :

- exit from the 1st B-channel 90%
- entrance into the inflector 90%
- accelerating radius R = 100 mm (no buncher) 36%
- final accel. radius R = 500 mm (no buncher) 10%
- final accel. radius R = 500 mm (with buncher) 40%

The coefficients concerning the accelerated beam are corrected to a duty factor. The beam losses on the grid of the buncher give 10%. The most serious losses are caused by a vertical divergence of the beam on the exit from the inflector.

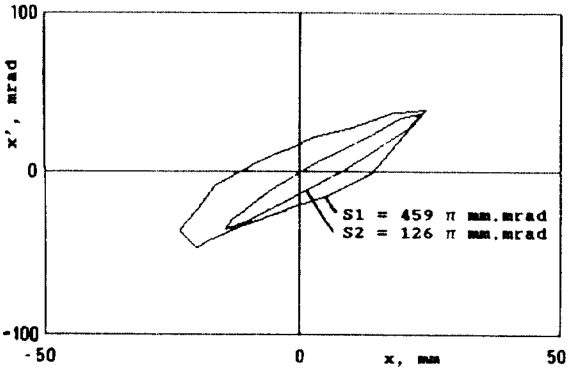

Figure 5. Measured figures of the injector's acceptances. (S1-without inflection, S2-with inflection and acceleration)

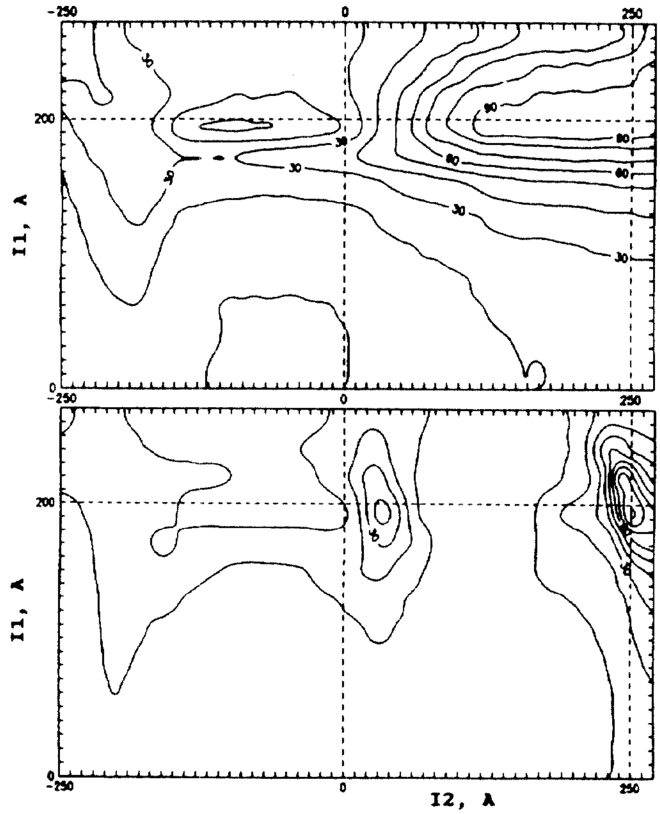

Figure 6. Relative values, in percentage of the maximal beam current, for different currents I1, I2 of two magnetic channels, (the upper diagram ... without inflection, the lower diagram ... with inflection and acceleration)

We measured acceptances by means of the bending magnet and the second correction magnet in two arrangements: the acceptance of the vertical line itself (S1) and the acceptance of the vertical line including the inflector and capture into acceleration (S2). Both acceptances were measured in the plane parallel with the edge of the dee (see fig. 5). The displayed characteristics are transformed to the entrance of the first magnetic lens in the first B-channel.

Interesting results were obtained from measurement of a relative beam value dependent on the currents I1, I2 in two magnetic B-channels (see fig. 6). These curves, in percentage of a maximal beam current, were measured for two arrangements: 1. without deflection to the central plane, 2. with inflector and capturing into accelerating process.

We estimated the phase width Φ of an accelerated beam without the buncher from the characteristic of a beam current on the dee voltage U_D. This characteristic is in a good agreement with the analytical relationship $\Phi = 2 \cdot arccos(U_{min}/U_D)$, see fig. 7. Measured values are denoted by squares, theoretical values denoted by solid line.

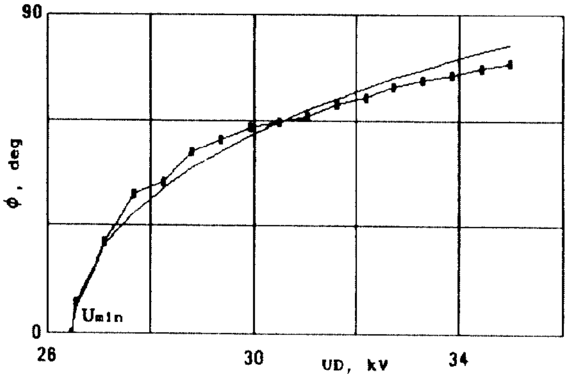

Figure 7. Characteristic of the phase width of a beam on the dee voltage.

5 CONCLUSION

At present, the testing of the injector for different regimes of acceleration continues and further characteristics are measured. We would like to test this system with a high intensive ion source – duoplasmatron. A heavy ion source is also beeing developed in our department.

6 References

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