EXPERIMENTS ON THE AXIAL INJECTION SYSTEM OF THE CYCLOTRON U-120M

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ABSTRACT

The basic parameters of the axial injection system of the isochronous cyclotron U-120M were tested using an ion beam of low emittance and intensity as well. The transmission of the 17keV deuteron beam including the capture into acceleration reached 40% while the transmission of the 19keV proton beam was only 12%. Several measured characteristics are presented and the connection with different injector efficiency is discussed.

1. INTRODUCTION

The isochronous cyclotron U-120M has been working in the Nuclear Physics Institute in Řež near Prague since 1977. It accelerates ions in the range of the mass to charge ratio A/Z =1–2.8 up to the maximal energy given by K=40. The physical and biological measurements are carried out there. About 30% of the operational time is scheduled for irradiation of the targets for the production of isotopes. The axial injection system[1)] installed on cyclotron in January 1992 will extend the cyclotron's experimental possibilities to the range of heavier ions, polarised ions and ions H^-, D^-.

The measurements were done in two different regimes: the first one for deuterons with maximal attainable energy 20MeV (regime D), that is very close to the regime for the acceleration of heavy ions and the second one for the protons of energy 25MeV (regime P). The main parameters of the accelerated ion beams of these two regimes are given in the table 1. The resulting coeficient of the transmission is 3.3 times higher in the regime D than in the regime P and it can be easily reproduced.

2. DESCRIPTION OF THE INJECTOR

The arrangement of the described injector[1)] is given on Fig. 1. Its basic components are: (1) - radiofrequency ion source with low emittance (normalized emittance 0.29 π mm·mrad), (2) - 5-gap acceleration structure supplemented by an einzel lens, (3) - 2000 l/s diffusion pump, (4) - the first correction magnet that compensates a stray magnetic field produced by the cyclotron, (5),(10) - diagnostic units consisting of Faraday cup, exchangeable collimation diaphragm of a circular shape and illuminated shade, (6) - double focusing bending magnet ($\alpha = 90^o$, $\beta = 26.5^o$), (7) - the two-gap first harmonic buncher, (8) - the second correction magnet with an adjustable orientation around the vertical axis, (9),(12) - the first and second water-cooled magnetic focusing B-channels, (13) - spiral inflector (Belmont-Pabot type) with an 8 mm gap between electrodes.

Table 1. Parameters of the accelerated deuterons (D) and protons (P).

ACCELERATED PARTICLES	D	P
energy of injection, keV	17	19
energy after acceleration, MeV	20	25
magnetic field in the cyclotron center, T	1.82	1.36
beam current measured between two B-channels, μA	6	22
beam current measured on the inflector, %	90	80
buncher switched off:		
accelerated beam current (R=100mm), %	36	6.8
accelerated beam current (R=150mm), %	19	5.2
accelerated beam current (R=500mm), %	10	2.8
buncher switched on:		
accelerated beam current (R=500mm), %	40	12
acceptance without inflection, mm·mrad	459π	398π
acceptance with acceleration, mm·mrad	$< 126\pi$	$< 65\pi$

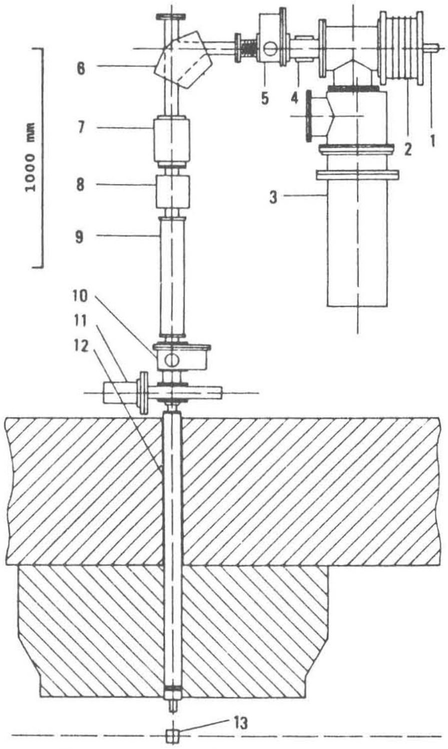

Fig. 1. Components of the axial injection system

3. EXPERIMENTAL RESULTS

3.1. Measuring of the acceptance

The acceptance of the system was measured by means of two equally oriented dipole magnets (6), (8) located in different distances before the entrance of the first B-channel (9). The point of the x-x'transverse phase-space plane which represents the center of the injected beam can be displaced in this plane in a wide interval employing these magnets. The characteristics of the injected beam current i_0 on the current I_c of the second correction magnet (8) were measured for different currents I_b of the bending magnet (6), see fig. 2.

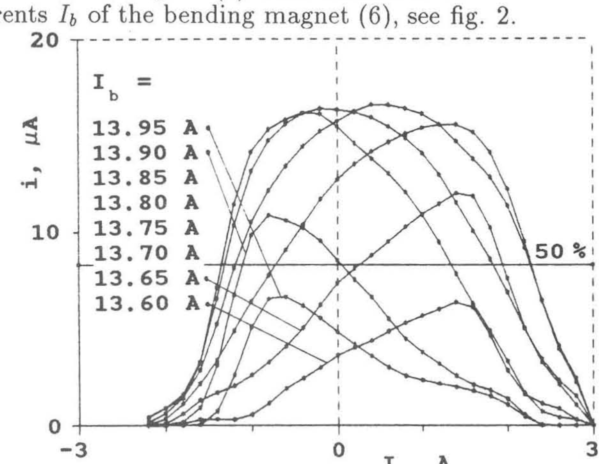

Fig. 2. Characteristics of the injected beam current i_0 on the current I_c for different currents I_b.

The acceptance of the injection line between the pair of the magnets and the place where the beam is measured was evaluated basing on these characteristics. We can see flat parts of the highest curves. They arise when the beam's emittance is fully placed inside the region of the acceptance. The points, where the measured current of the beam is 50% of the maximal current of the beam, correspond to the contour of the acceptance. For these measurements the beam current was measured on the bottom inflector electrode, negative voltage was connected to the upper inflector electrode. The measured acceptance demonstrate the focusing capability of the vertical line.

The acceptance of the whole system including capture and acceleration was considerably lower. In this case the flat parts are missing on the curves analogous to the curves on fig. 2. The measured characteristics represent rather the beam emittance. The acceptance is lower.

The acceptance figures for regimes D and P are shown on fig. 3. The larger areas represent the acceptance of the vertical line consisting of two magnetic B-channels together with an inlet diaphragm of the diameter of 7 mm. The smaller regions contain the acceptance of the whole system including acceleration. All graphs are calculated for the beam at the entrance of the first B-channel.

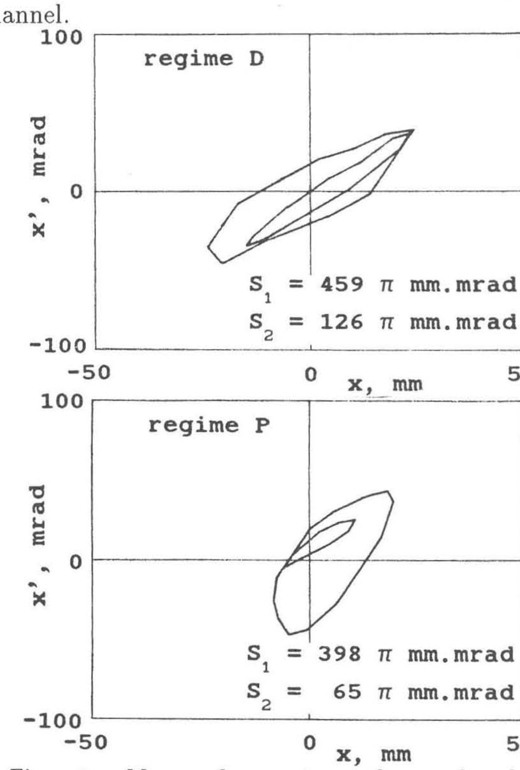

Fig. 3. Measured acceptance figures for the regimes D and P

3.2. Central region

The spiral inflector is the main element which determines setting-up parameters of the injector. The injection energy and optical elements of the whole injection

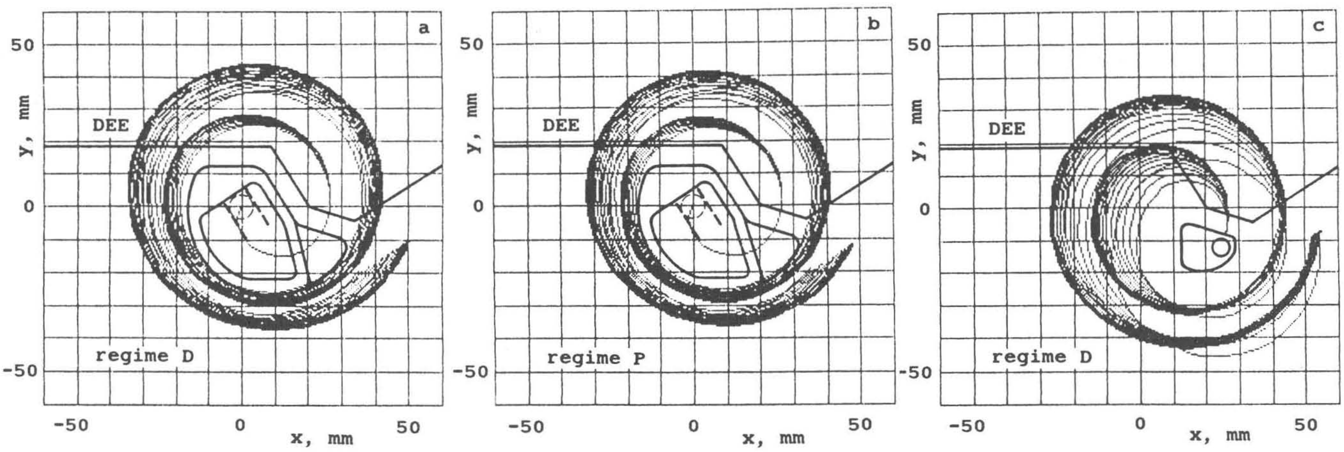

Fig. 4. Positions of the first beam orbits and the central regions in: a) regime D with inflector b) regime P with inflector c) regime D with inner ion source

line must be matched to its parameters. A supporting construction of our inflector had to enable us a simple replacement of the inflector with an inner radially mounted ion source without any additional constructional modifications. This is why the inflector was fixed to the supporting rods of the same construction like the rods of the inner radial ion source. The difference in positions of the beam orbits for the inner ion source and for the inflector is small. The amplitudes of betatron oscilations were reduced to the amplitude less than 2 mm in both regimes by a small correction of the current in the harmonic coils. Positions of the first uncentered beam orbits are shown on fig. 4. Three different figures are presented: a) injection of the deuterons (regime D) into the cyclotron by means of the inflector, b) injection of the protons (regime P) also with the inflector and c) extraction of the deuterons in regime D from the inner ion source. The ion trajectories were calculated for input h-f phases in the range from -45^o to $+45^o$ (step 5^o). The amplitude of the dee voltage was 34 kV.

One of the reasons for higher beam losses in regime P is the fact that a vertical emittance of the beam which exits from the inflector is not matched with a vertical acceptance of the cyclotron acceleration system.[2] This fact is obvious from the graph of the accelerated beam current i_{500} on the voltage U_{-inf} of the upper inflector electrode, see fig. 5. The displayed characteristics were measured by two methods: a) the beam current was tuned by the voltage U_{+inf} of the bottom spiral electrode and b) the voltage U_{+inf} was constant. The point marked by an arrow is the point in which the voltage of the spiral electrodes are the same but of the opposite sign. The flat parts of the curves would mean here, as well as in the measurements of the acceptance of the vertical channel, that the vertical cyclotron acceptance is bigger than the vertical beam emittance. These curves could be used for the determination of the vertical cyclotron acceptance. Because there are no flat parts, we suppose that there are enormous vertical losses of the beam on the first orbits.

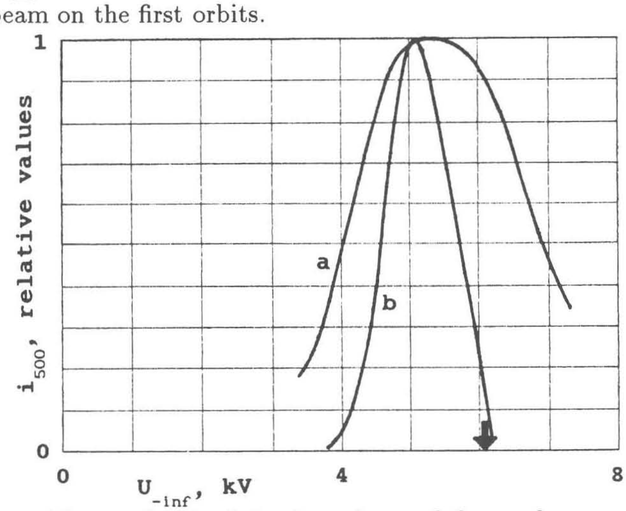

Fig. 5. Graph of the dependence of the accelerated beam current i_{500} on the voltage U_{-inf} for two cases: a) voltage U_{+inf} was tuned b) U_{+inf} was constant.

3.3. Beam in the magnetic B-channel

There are three elements used for focussing of the beam along the axis of the injection: the einzel lens placed in the acceleration structure behind the R-F ion source and the two magnetic B-channels placed in the vertical part. Magnetic B-channel is a classical solenoid supplemented by a system of cylindrical rings from ferromagnetic and nonmagnetic materials, alternately arranged in a row along the axis of injection. Maximum intensity of the transferred beam can be well reproduced. Characteristics of the accelerated beam current i_{500} on

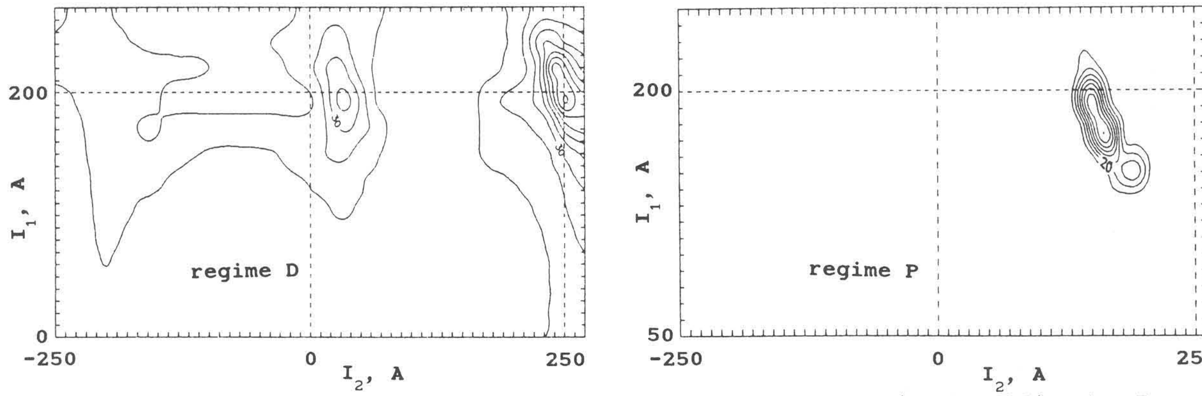

Fig. 6. Relative value i_{500} for different currents I_1, I_2 of two B-channels in: a) regime D b) regime P

currents I_1, I_2 in the first and second B-channels for D and P regimes are shown on fig. 6.

The resulting magnetic field of the second B-channel is a superposition of the monotonous component of the stray axial magnetic field in the central hole of the cyclotron yoke and the periodical axial magnetic field of the B-channel. In the regime D, when the magnet of the cyclotron is almost saturated, the monotonous component of the magnetic field in the second B-channel is much higher then in the regime P, see fig. 7.

Beam envelopes of the injected beam were calculated using the program TRANSPORT. These calculations were done for the transport of the particles from the interior of the inflector back to the entrance of the second B-channel, providing the beam is focussed at the center of the inflector. The envelopes differ in the number of wavelengths in the second B-channel, see fig. 8. The same character of the envelopes as in the more successful deuteron regime can be obtained in the proton regime only with current I_2, for which the coil of the second B-channel cannot be sufficiently cooled because of the small rate of water flow. Another possibility of improving the transmission for regime P is a vertical change of the position of the second B-channel. This change is

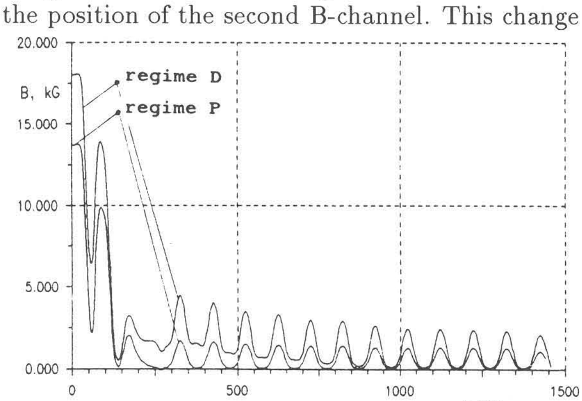

Fig. 7. Axial magnetic field along the axial hole of the second B-channel in: a) regime D (current of the cyclotron's magnet I_0=556A, current of the second B-channel I_2=250A b) regime P (I_0=279A, I_2=150A)

not possible without complex disassembly of the whole system.

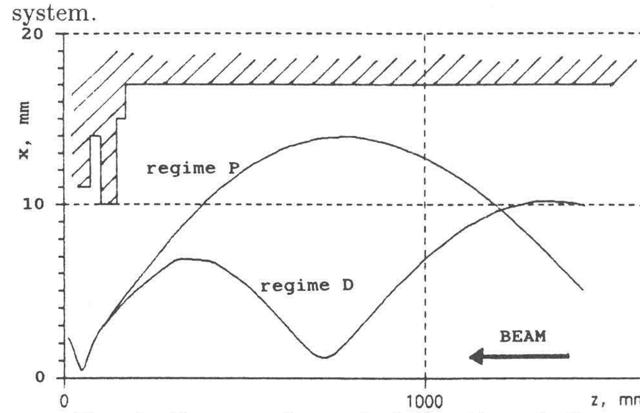

Fig. 8. Beam envelope calculation through the second B-channel in: a) regime D b) regime P

4. CONCLUSION

The basic parameter of the injector is a transmission efficiency of the injected beam from an outer ion source to the final cyclotron orbit. The transmission efficiency of our injector, measured for deuteron regime D with the beam of low intensity, gives a good chance to accelerate fully ionized particles, whereas the efficiency of the transmission in the regime P is approximately 3.3 times lower. The reason for the decrease of the transmission efficiency is bad matching of the beam emittance with the vertical acceptance of the accelerating system in the place of inflector. Installation of a correction quadrupole in front of the second magnetic B-channel would improve this situation. Another possibility is to change the position of the second B-channel with the respect to the strong magnetic lens created by the hole in iron plug at the entrance to vacuum chamber. The acceptance of the vertical line is sufficient.

5. REFERENCES

1) J. Štursa et al., The axial injection system of the isochronous cyclotron, Proc. Europ. Part. Accel. Conf., Berlin, Germany, 24-28 march, 1992
2) R. Baartman, Proc. Europ. Part. Accel. Conf., Rome, Italy, 7-11 June, pp.947-948.