A VERTICAL INJECTION SYSTEM FOR THE UNIVERSITY OF MANITOBA CYCLOTRON

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Abstract

A vertical injection system for the University of Manitoba cyclotron has been operational since May, 1975. Test results indicates that the beam transmission efficiency in conjunction with the use of a beam buncher is about 3% at 25 MeV and 1.5% at 40 MeV.

1. General Description

The University of Manitoba Cyclotron$^{1)}$ was built in the early 1960's mainly for acceleration of H$^-$ beams. It is of a compact type, with the magnetic field ranging from 1.6 to 2.6 Tesla, and 28 kV dee voltage at 28.48 MHz RF. With the pole tip radius of 60 cm it can provide up to 50 MeV of H$^-$ beam. The increasing desirability of polarized beam resulted in the design of a vertical injection system for this cyclotron. The design poses a number of difficult problems arising from the high flux nature of this cyclotron. The radius of curvature with an injection energy of 11 keV is only 8 mm in entering the cyclotron. This imposes a severe restriction on the height and width of the dee gaps as well as on the dee tips geometry. The design of the inflector is not a small problem. A strong leakage magnetic field all around the cyclotron imposes restrictions on the beam's vertical transport system. With these difficulties in mind a design study was started in April, 1974. The design was divided into two parts comprising a vertical transport system and the cyclotron central region. However, for the purpose of description we split it into four sections; the vertical transport system, the beam buncher, the inflector and the dee tips.

2. Vertical Transport System

Figure 1 shows schematically the vertical transport system. The H$^-$ beam is produced in a duoplasmatron H$^-$ source which is placed at the top of the transport system. The beam is extracted and then accelerated to 11 keV. At this point the beam is strongly divergent comprising approximately ±30° cone. An einzel lens and four sets of electric quadrupole triplets focuses this beam in such a way that waists are formed in between the ajacent triplets. The admittance is about 100 mm mrad. The last stage triplet is smaller in size but has much stronger focussing power. It is placed right above the entrance to the cyclotron central field of 1.87 Tesla. Thus as soon as the beam passes through this triplet it enters the cyclotron field and acquires a rotational motion arising from the electro magnetic momentum. By adjusting the strength of quadrupoles we equalize the amount of the maximum rotational motion to the divergence of the beam. Thus, with the beam phase space area of $A=\pi r_{max}(\frac{dr}{dt})_{max}$ the above requirement gives the radius of the beam envelope to be $r=\sqrt{\frac{2mA}{\pi eB}}$ where m the mass of H$^-$, e the electronic charge and B the magnetic field of the cyclotron in SI units. We then get a uniform column of beam with column radius of r. This is the condition for minimum beam centre spread on entering to the cyclotron field. With a beam of 100 mm mrad at 11 keV we get a beam with a uniform vertical column of 0.72 mm around the inflector region.

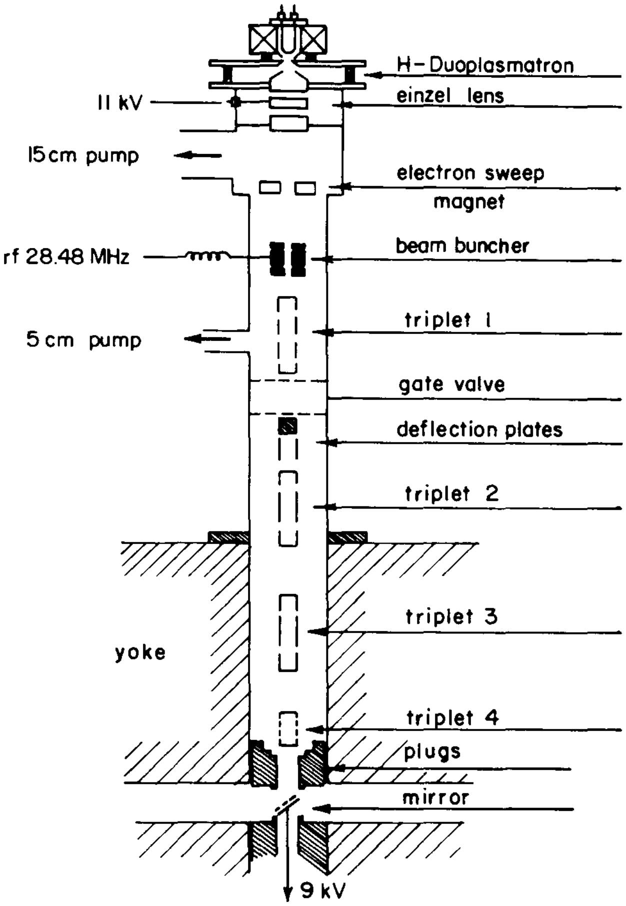

Figure 1 Schematic of new Injection System

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A pair of X-Y deflection plates correct the beam path. We found the electron sweep magnet nunecessary and it was therefore replaced by two pairs of X-Y deflection plates giving a greater degree of beam path correction. The whole system is displaced from the geometrical axis of cyclotron by 5mm to offset the displacement of the beam centre during the subsequent accelerations. There is a leakage magnetic field of up to 0.1 Tesla along the vertical transport system. We paid great care to make this leakage field rotationally symmetric along the central line of the system. The use of iron tubes eliminated any possible non-axial field component for most purposes. The triplets are rotated with respect to each other in accordance with the rotational motion of the beam along the path. Up to $40\mu A$ of H^- beam has been obtained on the inflector. The result of detailed computer studies will be presented in reference 2.

4. The Beam Buncher

A beam buncher of half wave length(2.5cm) was built and placed about 120cm above the inflector. We made a detailed computer study on the beam bunchong effect as a function of buncher RF voltage, the total path length and the width of RF phase acceptance of cyclotron. With a given condition of 20eV beam energy spread from the source the operational results showed that the buncher provides factor of 5 to 10 enhancement in the beam depending on its total current. The buncher,however, produces an additional energy spread of up to 400eV to the beam.

5. The Inflector

With the radius of curvature of only 8mm for the first quarter turn in the cyclotron we had to restrict the size of the high voltage electrode (which is at -9kV) to 4mm in radius, the inner radius of the ground potential electrode to 5.5mm and the thickness of it to 0.5mm. The face of the ground potential electrode is inclined at 46.3° and is formed by an array of 0.05mm thick tungsten wires threaded onto the ground potential electrode. The beam transparency is about 75%. We encountered a sputtering problem between the two electrodes. Some of the sputtered metal particles are deposited onto the surface of the supporting insulators and this eventually lead to the electrical breakdown of the inflector. We havent solved this problem completely but we found that insertion of a specially shaped insulator sleeve between the electrodes prolongs the life to one week(from six hours) before it breaks down. The replacement of it can be done without first venting the chclotron and this allows us to do the whole job in less than half an hour. We have remote control mechanism to move the inflector up and down and also to rotate it.

6. The Dee Tips

Figure 2 shows a model of the equipotential lines hypothetically produced by an assembly composed of two dee tips(top and bottom), the inflector housing(centre) and two wings at ground potential(left and right). The trajectory of an H^-ion under such an RF field configuration is also shown for the first ten turns. This was obtained for the starting conditions which are indicated in Table 1. Also shown in the table are the results of the beam motion at the 50th turn for selected points in the phase configuration. It is noted from the first entry in B that the distortion of the beam in x direction is quite large. This is caused by a resonance to ν_r =1 from the equivalent RF second harmonic component.seen by the beam. A more detailed study showed that about half of the distortion resulted from the gap crossing resonance and the remaining half from the curved nature of the dee tips. The distortion in the Y direction is seen to be much less than in the X direction. This was because the individual distortions on crossing the gap of the two dee tips tended to cancel each other for both types of distortions. It was found that changing the shape of the dee tips merely shifted the nature of the distortion from one type to the other and that there is a shallow minimum in the combined distortion. The shape

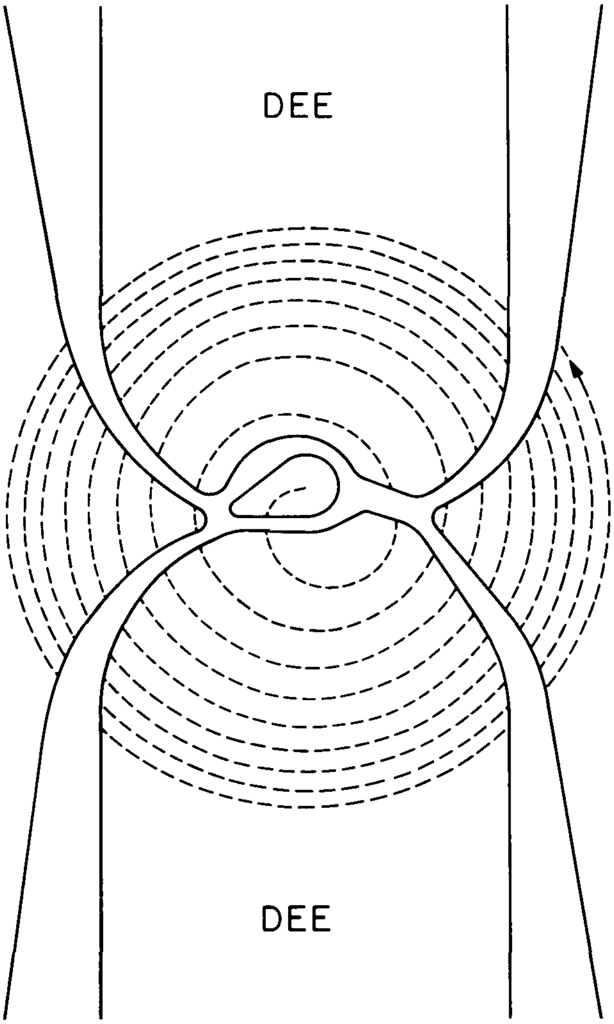

Fig.2. A set of equipotential lines and a beam trajectory of first 10 turns. The starting condition for this is shown in Table 1.

shown in fig.2 is not far away from this minimum. Also noticible is the phase debunching effect in the last entry. This effect is, however, partly offset by the increased compression afforded by the beam buncher.

For beam vertical motion preliminary calculation showed that after three turns of accelerations it is not far away from the adiabatic passage, $\frac{d\nu_z}{dn} \ll z$ A small magnetic field bump is provided for an additional vertical focussing(and for a better adiabatic passage) before 12cm radius. Of the first three turns the first three gap crossings were found to produce far too strong vertical focussing. We therefore decided to put vertical slits on each of these three gaps. Due to mechanical difficulty only the slit in the second gap has so far been successfully tried. We have ν_z varying between 0.16 and 0.27 between 12cm and 50cm of radius. Ideally, therefore, a beam with 100mm mrad on injection should have vertical spread of less than ±3mm in this region. The observed spread covers full height of the fluourescent screen (±10mm) indicating that the central region will require further attention in the future. The final shape of the dee tips was slightly modified from that which would produce the equipotential lines shown in fig. 2 to allow for easier construction. A fluourescent screen was used to investigate the beam's vertical motion. This screen was mounted on a remotely controled probe and with the aid of a television camera it was possible to observe the vertical motion from 5 to 43cm radius. From r=25cm to 50cm the cyclotron's stripper foil was used to read out the beam current. So far we get 1μA at 25MeV, 500nA at 40MeV, 250nA at 42MeV and 50nA at 50MeV. We estimate that the stripping loss of the H^- beam due to collision with the residual gas causes reduction of a factor of about 3 at 40MeV. Above 42 MeV electron stripping loss due to the motional electric field becomes serious. We observed that the beam starts a large vertical oscillation at r=10cm and this is probably caused by a radial component in the magnetic field. There are a number of other smaller but non-negligible factors which requires further attensions. At the moment a systematic investigation of the beam orbits is in progress. This includes a much more detailed mapping of the magnetic field and a three dimensional relaxation calculation of the RF field. A further diffusion pump is planned to be mounted to reduce the gas stripping loss.

Table 1. The beam dynamical properties at 50th turns of acceleration for selected points in the phase space. Entry A shows the initial condition for the reference ray.

	The reference ray	Mark-11 dee tips
A	beam injection energy	11keV
	dee bias voltage	-2kV
	RF voltage, peak to ground	27kV
	RF phase angle at which the reference beam is injected to the dee	-17°

	starting condition at the inflector	The results at the 50th turn(3.0MeV)
B	centre spread in X direction: dX_c= 1mm	dX_c= 3.3mm dY_c= 0.34mm dE = 10.2keV $d\Phi_{rf}$= 1.9°
	centre spread in Y direction: dY_c= 1mm	dX_c= 1.7mm dY_c= 0^1/07mm dE = 40keV $d\Phi_{rf}$= -5.4°
	spread in injection e energy: dE = 0.4keV	dX_c= 0.05mm dY_c= -0.05mm dE = 5.0keV $d\Phi_{rf}$= 0.8°
	injection phase advance from the reference ray: $d\Phi_{rf}$= -3°	dX_c= -0.25mm dY_c= -0.02mm dE = -56keV $d\Phi_{rf}$= -7.3°

References

1. J.J.Burgerjon, B.Hird, F.Konopasek, K.G.Standing, IEEE Transsactions on Nuclear Science NS-13 (1966) 422

2. To be produced in the 1975 NRC/AECB Annual Report.