BEAM DYNAMICS ASPECTS OF A HIGH INTENSITY ISOTOPE PRODUCTION CYCLOTRON

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Abstract

A high intensity 30 MeV H^- cyclotron [1] is under construction at the C.R.C. This paper deals with aspects of axial injection of intense H^- beams at low energy (30 kV), central region design and beam dynamics during acceleration in a magnetic field with high flutter, and extraction optics.

1. Magnetic field

Since this cyclotron is a fixed energy machine, the magnetic field can be very accurately shimmed to obtain the isochronous field and no correction coils are needed. The radial field profile is obtained by varying the width of the sectors. The nominal sector angle has been choosen to be 54 degrees (between effective field boundaries). This angle varies, due to shimming between a min of 50° at 40 cm to 56° at maximum radius. Figure 1 shows the operating line of the cyclotron in ν_R, ν_Z space. Due to the high flutter and small gap, the vertical betatron frequency rises very fast to about 0.6. Furthermore, all resonances are quickly crossed in one or just a few turns.

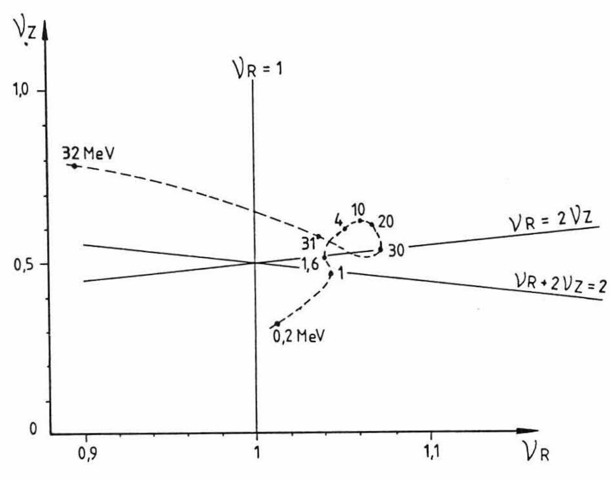

Figure 1
Operating diagram ν_R, ν_Z.

2. Injection line optics

The high intensity H^- source is mounted vertically on top of the cyclotron. Its distance to the yoke is determined mainly by the height of the diffusion pump. The H^- source however produces also some neutral beam. To avoid unnecessary heating and outgassing down the line, a system of 2 opposite 15 degree bending magnets has been installed below the source. This allows the displacement of the H^- beam from the neutral beam which is stopped on a target. The source emittance has been measured to be around 400 mm.mrad at 30 kV. The

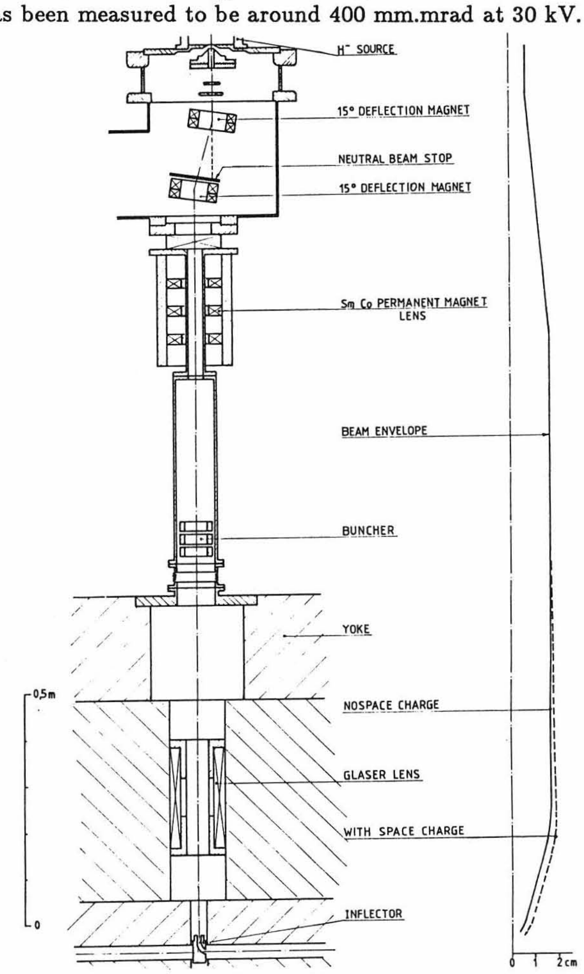

Figure 2
Injection line layout.

transfert line has been designed to accept up to 600 mm.mrad to allow for mismatch and beam blow up by space charge. At the other end of the line, the beam has to pass through the inflector and to be matched to the cyclotron centre acceptance, which requires a small and strongly converging beam (dia. 6 mm, 70 mrad). This transfer between source and inflector is done essentially by two lenses. A first lens using three rings of permanent magnets whose positions are adjustable (to allow adjustment of the lens strength) produce a quasi parallel beam. The beam is then refocused to a waist at the inflector entrance by an active Glaser-type lens. This solution has been adopted on the prototype cyclotron to allow easy adjustment and compensation of space charge detuning. When the influence of space charge will have been measured, this lens could be replaced by a fixed permanent magnet lens also. The layout of the injection line is shown on figure 2.

3. Central region - inflector choice

All calculations of beam centering have been performed with injection voltage around 30 kV. Dee voltage 50 kV, constant gap width 8 mm between dee and dummy-dee and homogenous magnetic filed 1.068 T were assumed. Optimum start point of R.F. phase is shown on figure 3 assuming 6 mm radial width of the beam at the start point and -/+ 20 degrees phase acceptance.

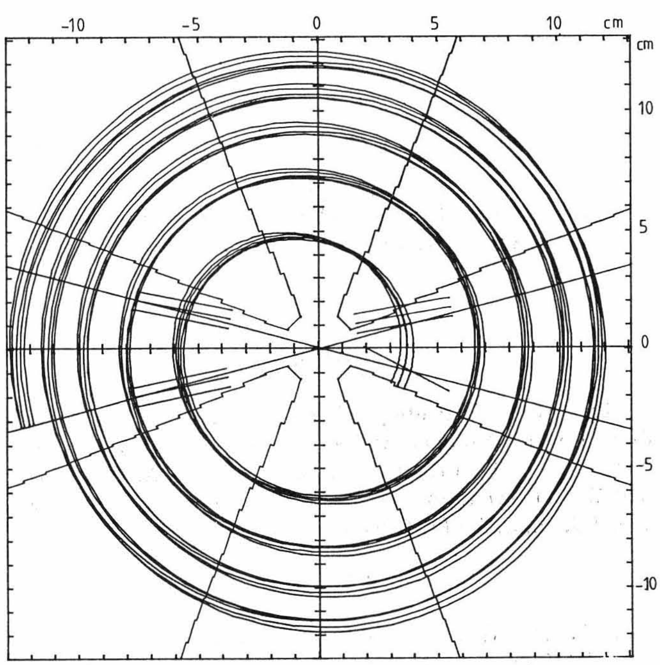

Figure 3
Turn pattern in the centre.

The vertical acceptance of the cyclotron was calculated to first order based on the paper by M. Reiser [2]. Figure 4 presents envelopes of a beam in the middle of accelerating gaps on five turns. Start parameters are : parallel beam 5.5 mm off the median plane and 35 mrad divergent beam from median plane. The beam coming out of the inflector can be fairly well matched to this acceptance since a drift between the inflector exit and the first gap allows the vertical amplitude to grow and the first gap is placed so as to be sufficiently focusing.

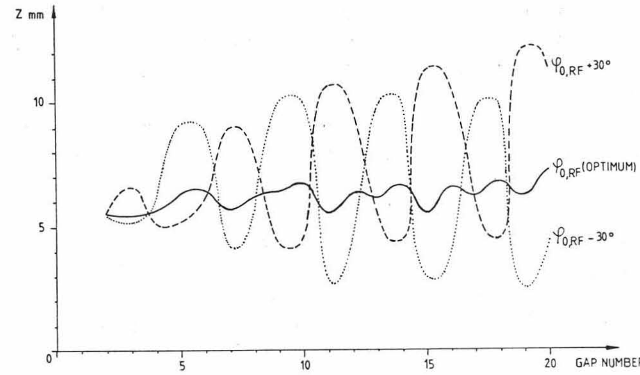

Figure 4
Vertical motion in the first five turns.

Once the conditions of the beam centering are calculated, a pseudocylindrical inflector [3] can be determined.

This gives severe constraints on inflector design. To achieve adequate centering of the beam it has to have electrodes tilted with respect to the median plane of the cyclotron.

Finally the chosen inflector has the following parameters :

- electric height (mm) = 40.5
- k' = tgθ (θ = max. electrode tilt angle) = - 0.334 (18.5°)
- magnetic radius (mm) = 23.4 ;
- voltage between electrodes (kV) = 11.9.

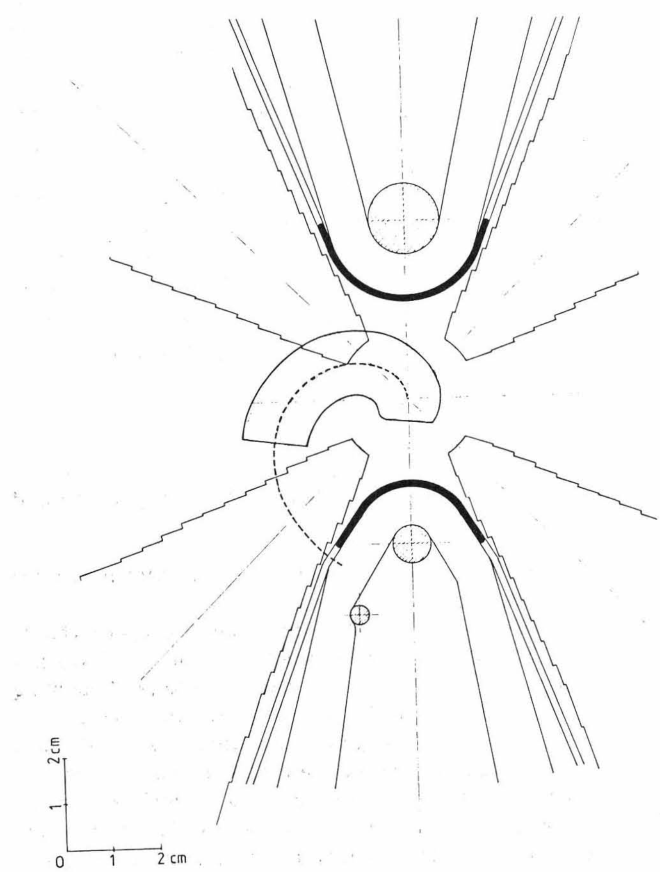

Figure 5
Inflector positioning.

These data correspond to an injection voltage of 30 kV. The width of electrodes is 12 mm. The distance between electrodes at the entrance to the inflector is 8 mm and it decreases to 7.2 mm at the exit.

The beam with an emittance about 200 π mm.mrad could be successfully transmitted by the inflector but the electric fringing field effects near electrode edges, at the entrance and the exit of the inflector have not been taken into account. The position of the inflector in the center of the cyclotron is shown on figure 5. One can see that the beam drifts 70 degrees between the inflector exit and the best start point.

The inflector electrodes are produced by high pressure forming of copper sheets. This allows to produce quickly several inflectors with the same parameters. A small thickness of electrodes is necessary to decrease vertical dimensions of the inflector and to make more space for insulation, connections and support systems.

4. Space charge considerations - Bunching

In the first part of the injection line (between source and buncher) it is expected that space charge will be neutralised almost completely by the presence of residual gas in the line. However as the beam tends to get bunched, charge density increases and neutralization decreases. Taking an average beam half width of 2 cm and a linearly increasing space charge force the new envelope of the beam has been calcualted. They are represented on figure 2. The lens power has to be increased by 15 percents to produce a waist at the same location as without space charge.

It appears that longitudinal debunching space charge forces are very important in the injection line and will be the limiting factor in the injection efficiency. The cyclotron R.F. phase acceptance is somewhere in the 40 ... 60 degrees range determined by vertical focusing. If no bunching at all is assumed this means a maximum injection efficiency of 15 percent. This could be increased to 45 percent by a simple gridded double gap klystron-type buncher, in the absence of space charge. Therefore, such a very simple buncher is located at 1 metre from the median plane. This is about the minimum distance since a shorter distance and hence a higher bunching voltage would result in a too important increase in vertical divergence after the inflector since this is very sensitive to energy spread. The characteristics for the 30 MeV H^- cyclotron buncher are :

- distance between gaps = 2 cm
- voltage amplitude = 700 V
- increase in vertical divergence = 6 mrad (on 70 mrad total)

Space charge effects can to some extent be compensated for by increasing the bunching voltage.

During the acceleration, the only effect of space charge which is of importance for this cyclotron is the vertical defocusing force. The longitudinal and radial effects (and coupling between these two motions) can, in opposition to cyclotrons with a classical extraction system and aiming at single turn extraction, be neglected because here, the turns are completely mixed. It is even desirable to have a beam which is homogeneous and with a relatively low luminosity. Calculations using formulae derived by Joho [4] show any way that the change of the transverse betatron oscillation numbers is of the order of 1 percent, even on the first turn.

5. Extraction

In order to verify the behaviour of the beam after extraction through the stripper foils, two cases have been calculated : one beam extracted at 30 MeV and another one at 10 MeV. Figure 6 shows initial and final emittance at the exit steering magnets in both planes. It can be seen that in all cases, the total beam dimension never exceeds 2 cm in any direction.

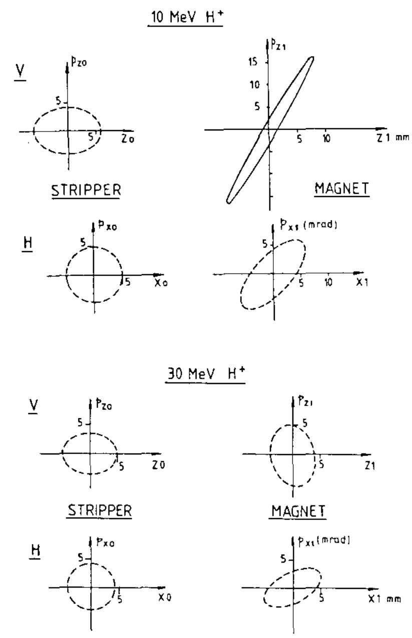

Figure 6
Emittance at the stripper and the deflecting magnet of the extracted beams at respectively 10 and 30 MeV.

6. Aknowledgements

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