DESIGN OF FOCUSING CHANNEL USING TRIPLET IRON BARS FOR CALCUTTA CYCLOTRON

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ABSTRACT

Particle beams in a cyclotron during and subsequent to extraction travel appreciably a long distance in the fringing field, affecting the beam quality by dispersion and defocusing. For 224 cm cyclotron at Calcutta these effects are evaluated. Constrained to find an element which would fit in the volume available, a passive channel consisting of three iron bars is explored. The effect of such a channel is estimated.

INTRODUCTION

Beams in cyclotron have to pass through the fringing field before entering the beam line. The adverse effects of such a field include growth in emittance when measured at the exit, consequent beam handling problems and a possible reduction in beam transferred to beam transport system. It would require a large quadrupole aperture to accept the beam. Many cyclotrons have introduced measures to counteract this effect . Methods to reduce the adverse effects include magnetic field shielding channels, magnetic focusing channels using coil and iron alone or a combination of the two.[1-4]

The cyclotron at Calcutta is a variable energy cyclotron which has been delivering beams. The centre has an active program to use ECR source. It is important to improve the characteristics in the fringing field to get better overall efficiency.

Use of triplet iron bars present an option simple in design and the advantage of the equilibrium trajectory remaining almost the same compared to the trajectory without the channel. Also, a steering magnet at the entry of the beam line would have been useful. The iron bars can be used to make small change in the trajectory. This configuration is explored for Calcutta cyclotron.

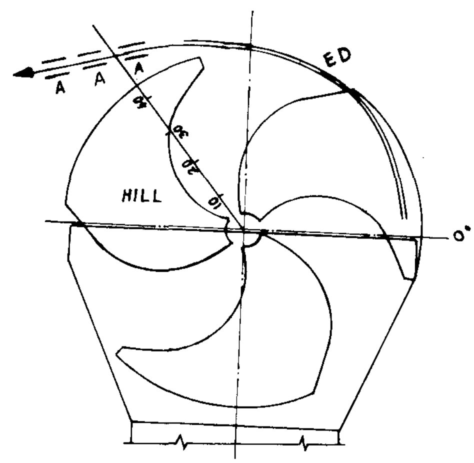


Fig 1. Schematic diagram of the cyclotron. The scale shown in the figure is in inches. The extraction is at 39 inches. ED is the electrostatic deflector spanning 3 degrees to 111 degrees azimuthally. AA is the possible location of the triplet iron bars starting at 121 degrees azimuth. The entry to the beam line is at 148 degrees. The beam bends by 4.6 degrees from the start of the channel to the exit. The distance between extracted beam and inside beam is 32 cms at 121 degrees.

THE FRINGING FIELD

To study the fringing field the field distribution corresponding to 64 MeV alpha was chosen. The effect of the field which is non-linear can be represented by a linear approximation.

If $X = (x, x', y, y', \Delta p/p)$ where x(y) and x'(y') are horizontal (vertical) displacement from the central trajectory and divergence and $\Delta p/p$ is the fractional change in momentum then for transfer from location 0 - 1

$$X_i\ (1) = \sum R_{ij}\ X_j\ (0)$$

where $R_{ij} = \delta X_i\ (1) / \delta X_j\ (0)$

The transfer matrix obtained in the units of cms, mrad, $\Delta p/p$ percent at the exit of deflector and the exit of the cyclotron from the entry point of the deflector are given by

$$\underset{(112^\circ/3^\circ)}{R} = \begin{bmatrix} 3.35 & 0.46 & 0 & 0 & 3.4 \\ 54.2 & 7.74 & 0 & 0 & 62.8 \\ 0 & 0 & -0.57 & 0.02 & 0 \\ 0 & 0 & -2.54 & -1.68 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

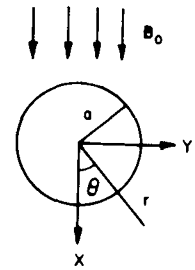
$$\underset{(143^\circ/3^\circ)}{R} = \begin{bmatrix} 10.3 & 1.44 & 0 & 0 & 10.8 \\ 100.5 & 14.20 & 0 & 0 & 113. \\ 0 & 0 & -0.48 & -0.12 & 0 \\ 0 & 0 & 2.68 & -1.41 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The envelope in fig. 2 shows that the horizontal beam extent increases considerably towards the end owing to dispersion and defocusing. The measurements with the radial probe located after the electrostatic deflector shows a beam spread of about one inch. Beam impression obtained 1.25 metres away from this probe (just after exit of the cyclotron) fills the whole beam line aperture of 4 inches. Even deflector instabilities can contribute to the spread.

TRIPLET IRON BARS

The triplet iron bars which have the configuration of one inner iron bar placed in the median plane and two iron bars placed above and below the median plane have the property of reducing the main field near the inner iron bar and adding to the field near the outer iron bars. The contribution to the field goes from positive to negative and hence the central trajectory can be matched.

An infinite cylindrical iron bar can be considered to have uniform magnetization when placed in a uniform magnetic field. The field distribution of a cylindrical iron bar can be calculated[3] analytically by



$$B_x(r,\theta) = B_0 + \frac{a^2}{r^2} B_0 \cos 2\theta$$

where B_0 is the external field directed along x, a is the radius of the bar and B_x is the component of field along x direction. With three bars the aperture and the radii can be chosen to get almost linear gradient of the field and "centre" the distribution. Table 1 gives the characteristics of the set up. The channel is split into three sections with 5 cm separation.

The parameters of the set up is dictated by the consideration of having small perturbation on the circulating beam. The first harmonic introduced can be corrected by the valley coil located near the extraction region. The nearest distance of the channel from the circulating beam is 32 cms, and the field perturbation $\Delta B/B$ at the radius where radial betatron frequency $\nu_r = 1$ is less than 3.5×10^{-4}. The trim and valley coils should be able to correct the disturbance.

TABLE 1. Characteristics of the setup

channel	inner(outer) bar diameter in mms	aper-ture in cm	cycl. field in KG	field grad. G/cm
1	20(30)	6	3.12	560
2	30(30)	8	2.25	302
3	35(40)	10	1.1	130

The R-matrix calculated shows the effect of such a channel for the above set up.

$$\underset{(143^\circ/3^\circ)}{R} = \begin{bmatrix} 6.7 & 0.94 & 0 & 0 & 7.5 \\ 17.7 & 2.6 & 0 & 0 & 24.2 \\ 0 & 0 & -0.87 & -0.15 & 0 \\ 0 & 0 & -6.0 & -2.15 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The envelope with the channel is also indicated in fig. 2 by H2 and V2. Since the gradients are not too large, the change in virtual source position will not require any change.

RECTANGULAR IRON BARS

Iron bars with rectangular cross-section have also been investigated. Though analytical

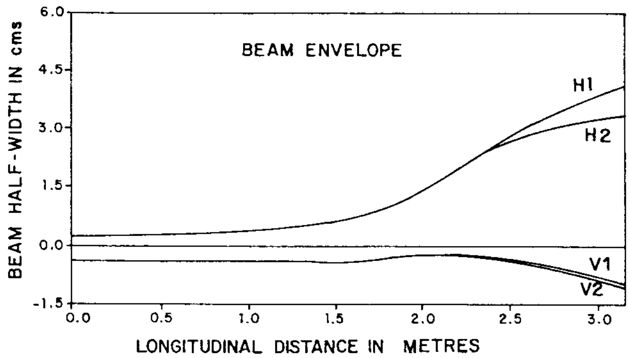


Fig. 2. Beam envelope with and without channel. H1, V1 (H2, V2) are horizontal and vertical envelopes without (with) channel. The initial ellipses are 5π mm mrad and 20π mm mrad for horizontal and vertical respectively. Δp/p=0.25%

expressions for finite rectangular bars with the assumption of uniform magnetization (when saturated) does not hold at low fields (1-5 Kgauss), POISSON code can be used to make estimates. The code was used to obtain the field distribution in the channel with the bars being located in the uniform field region. The permeability table used was the one built in POISSON package for low carbon steel.

The field distribution in the effective region of the channel is in close agreement with the analytical formula if an assumption that magnetization can be ascertained from the iron-field is made. Fig. 3 gives the comparison where field distribution in the median plane at the centre of the bar is compared. The right hand scale gives vertical height in cms. The iron region is shown shaded.

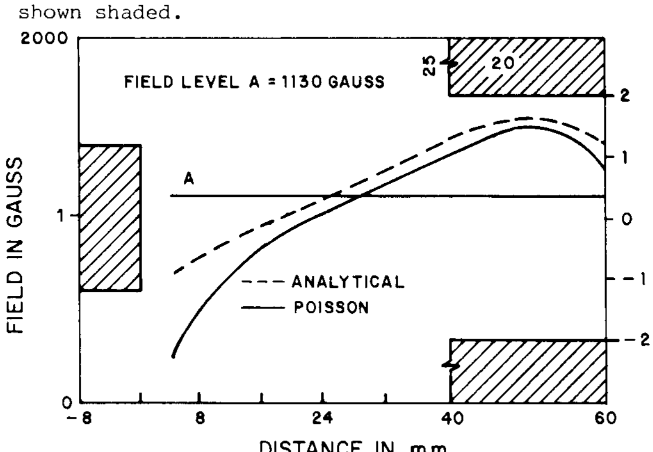


Fig 3.

A set of parameters for the iron bars have been obtained where inner bars have 8 x 25 mm^2 cross-section while outer bars have increasing cross-section, once again, to " centre " the field profile. The first harmonic at y/r = 1(37 inches) location is less than 1 gauss.

CONCLUSION

The effect of the fringing field is evaluated for Calcutta cyclotron. And a conceptual design of using triplet iron bars as magnetic focusing channel has been presented. The simulations suggest that these can be used to improve the beam quality in the fringing field of the Calcutta cyclotron. Existing correction coils seem to be adequate to compensate the field disturbances in the region of circulating beam.

References

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