© 1993 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

Beam Transport Line of CIAE Medical Cyclotron and Its Magnetic Elements Design Studies

Tianjue ZHANG   Chenjie CHU   Mingwu FAN

China Institute of Atomic Energy
P.O. 275(3), Beijing, 102413, PRC

Abstract

More than 300 μA proton beam has to be transported from exit of a cyclotron to target. The final beam spot less than Φ8 mm in diameter was asked. To reduce the cost of the system the beam aperture is limited to 50 mm in diameter and the magnetic elements are carefully designed with easier fabrication and loose tolerance. For example, the cross section of the pole faces of the quadrupoles are broken line shaped instead of hyperbola. And the two steering magnets have been added to control the vertical and hozizontal position of the beam on the target.

I. INTRODUCTION

CIAE Medical Cyclotron is a fixed–field, fixed–frenquency cyclotron. It is built to produce short–lived radioisotopes. Its vault and target room is showen in fig. 1. More than 300 μA proton beam has to be transported from exit of the cyclotron to target for isotopes production. The beam line for this purpose is being built in CIAE.

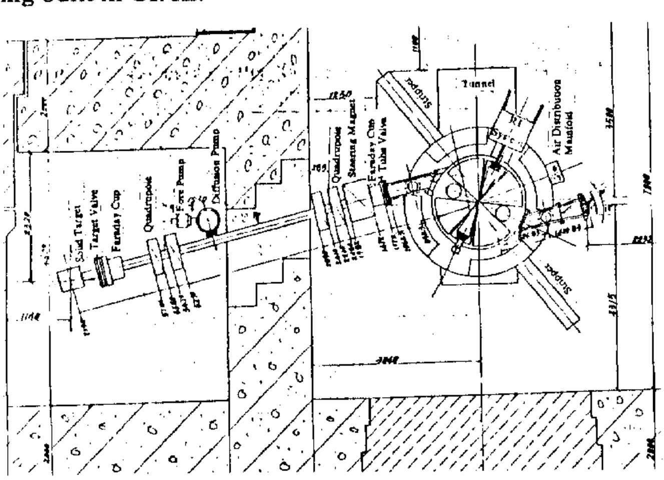

Fig. 1 The vault and target room

II. BEAM LINE DESIGN

The beam is able to be extracted form the cycltron after H^- ion stripped cross a thin carbon foil. The proton is bent out of the cyclotron by the edge field. The stripper is radially and azimuthally adjustable, that make the extracted beams at different energies are directed towards the centre of the switching magnet. To reduce the cost of the system the beam aperture is limited to 50 mm in diameter. In order to meet the requirement of the final beam spot less than Φ8 mm, two pairs of quadrupole are used instead of a triplet or a pair of quadrupole [1,2]. Two steering magnets are used to control the vertical and horizontal position of the beam on the target. The bending angle is more than 2 °.

After stripper, the beam emittance is provied as:

$$\varepsilon_x = 8.4 \times 6.38 \times 10^{-6} \mathrm{m.rad}$$

$$\varepsilon_y = 2.7 \times 6.25 \times 10^{-6} \mathrm{m.rad}$$

The beam line is designed based on the code TRANSPORT.

For 30MeV beam , the results are:

1. The maximum of envelope in X direction is limited in 24.87 mm, in Y direction 17.77 mm.
2. Position of the elements is showen in fig. 1.
3. In the working condition ,the magnetic field gradients are:

$$K_1 = -0.57605 \mathrm{kG/cm}$$
$$K_2 = 0.57308 \mathrm{kG/cm}$$
$$K_3 = -0.66457 \mathrm{kG/cm}$$
$$K_4 = 0.72957 \mathrm{kG/cm}$$

For 20MeV beam , the results are:

1. The maximum of envelope in X direction is limited 24.40 mm, in Y direction 21.19 mm.
2. Position of the elements is the same as above.

0-7803-1203-1/93$03.00 © 1993 IEEE

3. The magnetic field gradients are :

$$K_1 = -0.44126 \text{kG} / \text{cm}$$
$$K_2 = \ 0.45866 \text{kG} / \text{cm}$$
$$K_3 = -0.57052 \text{kG} / \text{cm}$$
$$K_4 = \ 0.63962 \text{kG} / \text{cm}$$

The envelope of different energy ion are showen in Fig. 2.1 and Fig 2.2.

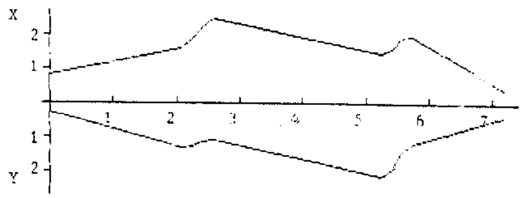

Fig. 2.1 30MeV beam envelope

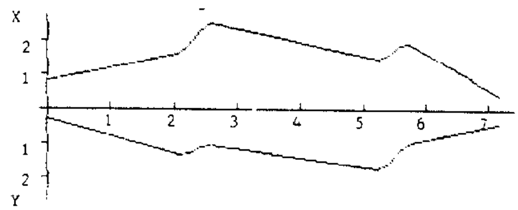

Fig. 2.2 20MEV beam envelope

Ⅲ. Quadrupole Design

In order focus the bean successfully ,the magnetic field distribution in quadrupole should be:

$$\frac{dB_X}{dy} = \frac{dB_Y}{dx} = const.$$

Therefore, the cross section of the pole surface should be hyperbola supposing $\mu \to \infty$. To avoid the different in the fabrication , the cylinder face is usually used instead of hyperbola in many cases. Based on the precise results of the magnetic field computation code, the broken line shaped can be used instead of hyperbola for the quadrupole. One eighth dimension of the quadrupole is showen in fig 3. The magnetic field distribution from DE2D software package are showen in fig. 4 . Three dimensional results of magnetic field computation (by DE3D) are showen in fig. 5 and fig. 6. It can be seen that the magnetic field gradients dB_Y / dx are close to const. in region [0,3]. Fig. 7 and fig. 8 show the mapping results. The different gradient can be obtained from −1 kG / cm to 1 kG / cm useing adjustment near of the current. Fig. 9 shows the quadrupole .

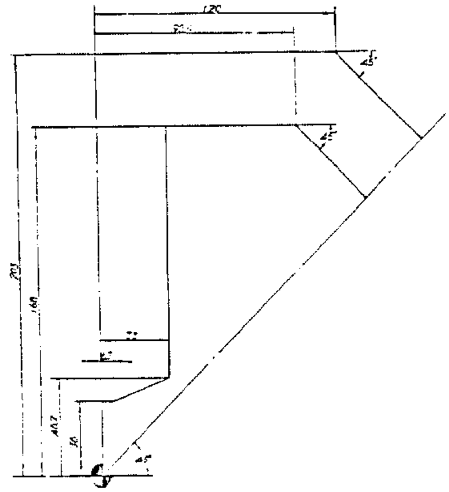
Fig. 3 The one–eighth of the quadrupole

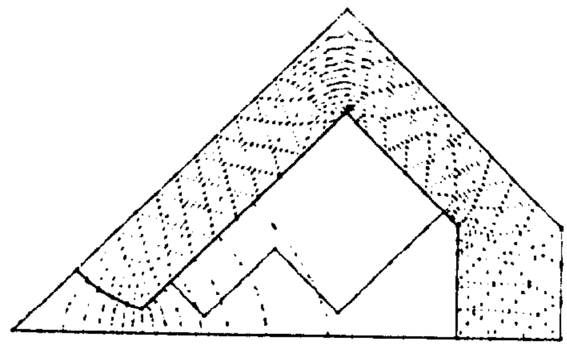
Fig. 4 The magnetic field distribution computed by DE2D

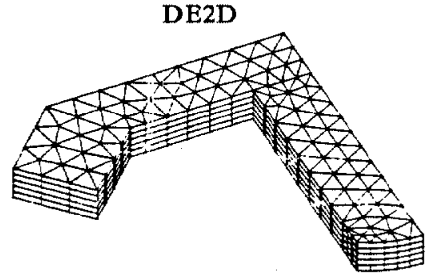
Fig. 5 The three dimensional mesh of the iron region

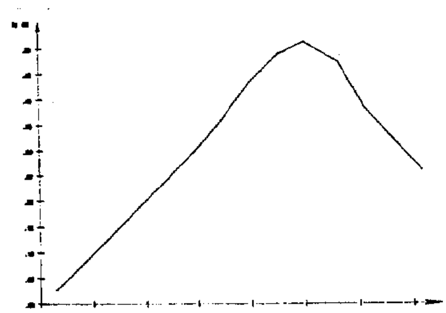
Fig. 6 The magnetic field gradient computed by DE3D

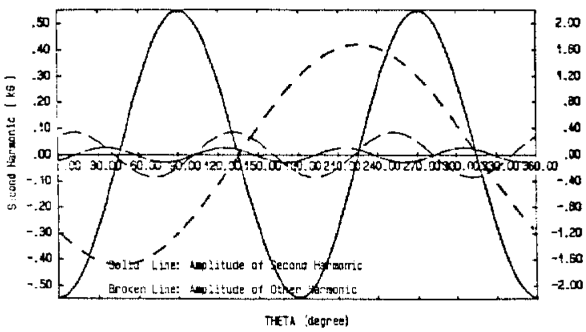

Fig. 7 The mapping results —— harmonic field

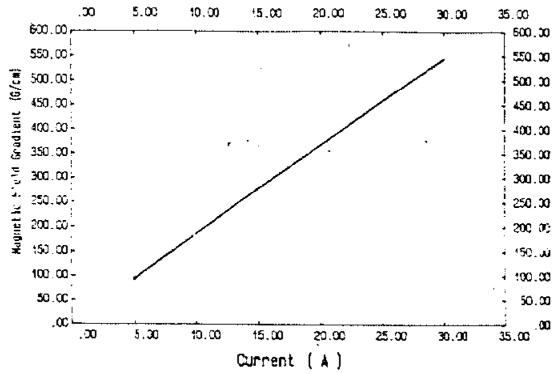

Fig. 8 The mapping results —— magnetic field gradient

Fig. 9 The quadrupole

IV. STEERING MAGNET DESIGN

In order to adjust the the vertical and horizontal position of the beam on the production target, two steering magnet are designed. The central the beam position ± 20 cm in the target.

The structure of steering magnet showed in fig. 11 . The pole breadth of steering magnet is 12 cm. The gap height is 7.2 cm.and the effective length will be approximately equal to:

$L_{eff} = 12+2 \times 0.65 \times 7.2 = 21.36$ (cm)

The computation results of magnetic field distribution is showed in fig. 12. The field indensity in the gap is 1521 G given by computation and measurement. With the beam energy 30 MeV, the rotated angle is

$$R = \frac{m_0 c}{qB} \sqrt{(2 + \frac{K}{E_0})\frac{K}{E_0}} = 5.2448(m)$$

Where K is kinetic energy. E_0 is rest mass. Then the beam bending angle is 2.3331 ° and the movement on target is 22.26 cm. magnet .

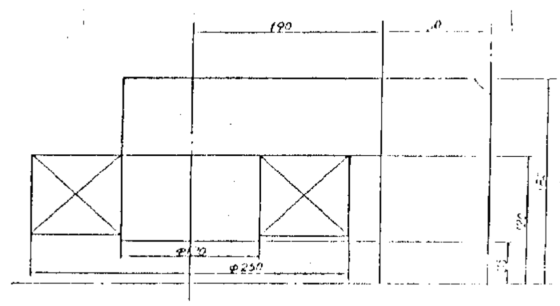

Fig. 10 The structure of steering magnet

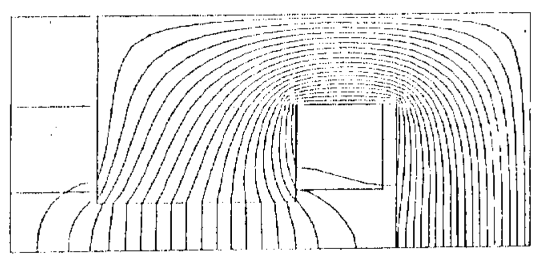

Fig. 11 The magnetic field distribution of steering magnet

V. CONCLUSION

The beam transport line is designed according to the requirements.

All magnetic elementsc possess same common characteristics: easier to machine, loose tolerance and lower power consumption et al.