# 270° ELECTRON BEAM BENDING SYSTEM USING TWO SECTOR MAGNETS FOR THERAPY APPLICATION

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*Abstract*

The 270 degree doubly achromatic beam bending magnet system using two sector magnets has been designed mainly for treating cancer and skin diseases. The main requirements of the design of two magnet system is to focus an electron beam having a spot size less than 3 mm × 3 mm, energy spread within 3% and divergence angle ≤ 3 mrad at the target. To achieve these parameters the simulation was carried out using Lorentz-3EM software. The beam spot, divergence angle and energy spread were observed with respect to the variation in angles of sector magnets and drift distance. From the simulated results, it has been optimized that the first and second magnet has an angle 195 degree and 75 degree and the drift distance 64 mm. It is also observed that at the 1396, 2878 and 4677 A-turn, the optimized design produces 3324, 6221 and 9317 Gauss of magnetic field at median plane require to bend 6, 12 and 18 MeV electron beam respectively. The output parameters of the optimized design are energy spread 3 %, divergence angle ∼ 2.8 mrad and spot size 2.6 mm.

## INTRODUCTION

Radiotherapy using electron and photon represent a most diffused technique to treat tumor diseases. With the advent of high energy linear and circular accelerators, electron / photon have become a viable option in treating superficial tumors up to the depth of about 5-10 cm. In such case, the dose of radiation absorbed correlates directly with the energy of the beam and its deposition of energy in tissues, which results in damage to DNA strands and diminishes the cell's ability to replicate indefinitely. For the last several years, electron accelerators are extensively being used in the medical field with special applications of photon and electron beam for cancer therapy and various skin diseases [1].

High energy medical electron linacs are usually mounted horizontally because of larger length of linac tube. The emergent electron beam from the accelerating tube is deflected magnetically through 90° or 270° into a vertical plane to hit an X-ray target or electron scatterer [2]. A small, stable, and axially symmetric beam spot on the target is needed. For fully rotational medical electron linacs, it is necessary both to minimize physical height of the machine and to maintain 100 cm distance between the x-ray target and rotational centre. In addition, it is also a basic requirement that the bending magnet is doubly achromatic i.e. the position and angle of the output beam is independent of input beam energy.

The 90° deflection system can bend a mono-energetic beam on axis to a point at the X-ray target, but the spread of energies of the actual beam results in a spread of such focal point at the X-ray target. Also, the radial displacement and angular divergence of the entrant beam results in spread of exit beam. To overcome the above problems a 270° bending magnet system is used. This system is doubly achromatic and can be made using one, two and three magnets [3]. Based on the orbit dimension and size, two dipole bending magnet system is advantageous. Therefore, an objective of the present paper is to provide a 270° beam bending using two dipole magnet system in which first bend is with 195° and other bend is with 75° to minimize the height of the orbit above the accelerator beam line.

## MATERIALS AND METHOD

The linear electron accelerator available at Society of Applied Microwave Electronics and Engineering Research, Mumbai having energies 6,9,12, 15 and 18 MeV [4], average current 80 $\mu$A, pulsed current 130 mA, pulsed width 6 $\mu$s, repetition rate 150 PPS is going to be used for the present study. The linear accelerator produces beam of 6 to 20 MeV with energy spread of 7%.

The Lorentz-3EM software has been used for studying the trajectory of charged particles through electric and/or magnetic fields in three dimensional geometry. The magnetic field between the poles and trajectory for various electron energies have been calculated with the help of Lorentz-3EM software for better accuracy.

## MAGNET DESIGN

In order to take advantage of the low height of an elementary single dipole and at the same time take advantage of achromatic system, a double focusing doubly achromatic magnet system was designed. It consists of two dipole magnets which are used to bend the 6 to 20 MeV

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energy electron beam by 270° onto the X-ray target within the acceptable geometry. The main requirements of the design of magnet system is to focus the electron beam, having a spot size less than 3 mm diameter, beam energy spread within $\pm$ 3% and divergence angle $\leq$ 3 mrad on the X-ray target.

The magnet system consist of two magnets, out of which one magnet deflects the electron beam by an angle greater than 180° and other magnet by less than 90°. If a finite energy spread beam is injected into a magnet with more than 180° deflection (first magnet), the output beam will be convergent. If the same beam is injected vertically upwards into a less than 90° deflection magnet (second magnet), the output beam would be diverging beam. The amount of convergence and divergence of beam is depending upon the bending angle of each magnet and the pole face angle at the exit edge of first magnet and entrant of the second magnet. [5] Therefore, simulation has been carried out using Lorentz-3EM software for compensating the convergence angle with divergence angle and choosing the appropriate drift distance between both the magnet.

## SIMULATION

For this, at first design the two sector magnets of angle 180° and 90° having radius of curvature 65 mm and the drift space between both the magnets was taken 65 mm. The schematic for simulation is shown in Fig. 1. Then, an electron beam of diameter 3 mm, energy spread of $\pm$ 7%, Gaussian profile in intensity was made incident on the pole face of first magnet. The incident electron beam parameters were adjusted such that it should match the actual electron beam from Linac tube.

The output beam coming out from the second magnet was detected at the bremsstrahlung target position which is kept at 70 mm $\pm$ 3 mm from the exit pole face of second magnet. The energy spread, beam divergence, and spot size of the beam were observed at bremsstrahlung target. For both the magnets, a common yoke of H-shape has been designed. The Steel 12L14 material was used for yoke and magnets. Both sector magnets have common magnetizing coils which has internal water cooled system. The pole gap between dipole magnet was kept 10 $\pm$ 0.1 mm.

The requirements of the design are (a) the central electron beam should remain perpendicular to the target surface at the distance of 70 mm from the exit edge of the second magnet. (b)target beam spot should be less than 3 mm. To achieve these requirements, the magnet angle and drift distance were varied in Lorentz-3EM. From the variations, it has been observed that as the magnet angle increases the beam angle with respect to target also increases. Moreover, as the drift distance increase the beam spot size decreases up to $\sim$ 2.8 mm at a drift distance of 64 mm and further with increase in the drift distance the spot size increases. From these results, it has been optimized that the first magnet of an angle $\sim$195°, second magnet of an angle $\sim$75° and the drift distance $\sim$64 mm $\pm$ 1 mm. The variation in current passing through the coil gives different values of magnetic field. To compensate and to bend the desired energy of electron beam, a current was accordingly adjusted for the measurement of output parameters. A cross sectional view of the optimized two magnet system is shown in Fig. 2 for 270° beam bending.

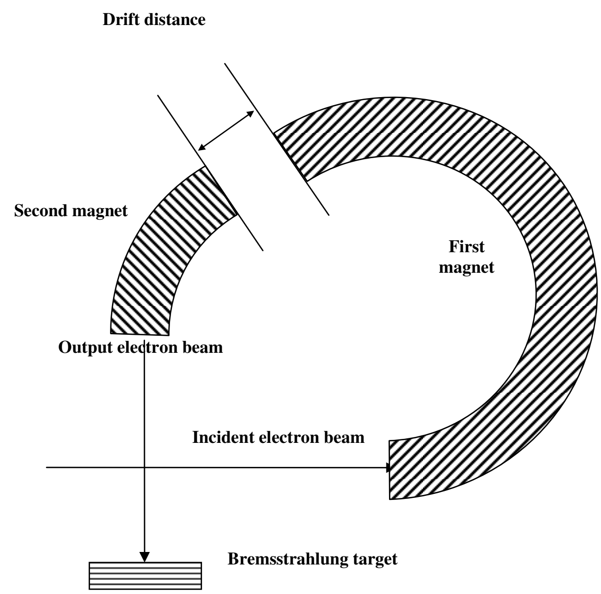


Figure 1: Schematic of simulation setup for two magnet system (Not to the scale)

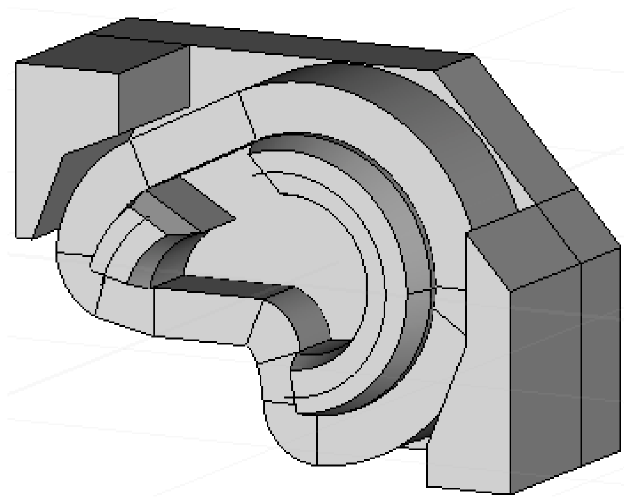

Figure 2: A view of proposed two magnet system

The width and height of the optimized magnet pole pieces are 37 mm and 70 mm respectively, taking into the consideration of the fringing field effect on the electron beam. The contour of magnetic field distribution in the magnet at median plane is shown in Fig. 3. Contour shows the uniform contribution of magnetic field over the pole pieces.

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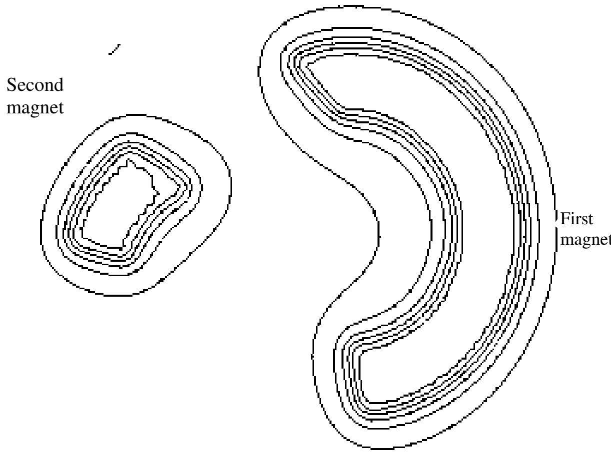


Figure 3: Contour of magnetic field distribution in the median plane of the first and second magnet.

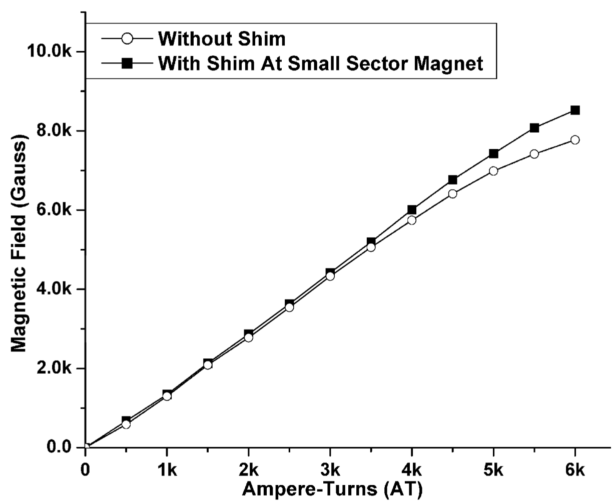


Figure 4: Variation in magnetic filed with ampere-turn with and without triangular shim at second magnet.

## RESULTS AND DISCUSSION

The optimized design of two magnet system does not fulfill the requirement of actual medical Linac for therapy. So the variation of magnetic field and other output parameters due to incorporation of triangular shim, trim coil and energy defining slit in the magnet system have been studied.

The initial magnetic field versus current measurements observed that the second magnet saturated more at higher current than the first magnet. Therefore, a triangular shim was introduced at the base of second magnet. The variation in magnetic field with amp-turns for with and without triangular shim at the base of second magnet is shown in Fig. 4. It is observed from the figure that with an introduction of triangular shim the magnetic field increases and further gets saturated with increase in the total amp-turns.

To make slight corrections in the angle and /or the position of the beam on the target, a set of trim coils have been added to the second magnet. Very small amount of current require to be passed through these coils. The magnetic field change produced due to trim coil has been estimated and it is shown in Table 1. From the table it is observed that ∼3% field change is obtained with 135 Amp-turns/coil of trim coil.

Table 1: Effect of Trim Coil on Second Magnet

| I (A/coil) | NI (/coil) | B (G) | Δ B (G) | % change (%) |
|---|---|---|---|---|
| 0 | 0 | 6605 | 0 | 0 |
| 1.50 | 30 | 6695 | 90 | 1.36 |
| 2.65 | 53 | 6717 | 112 | 1.69 |
| 4.00 | 80 | 6743 | 138 | 2.09 |
| 5.25 | 105 | 6770 | 165 | 2.50 |
| 6.75 | 135 | 6805 | 200 | 3.03 |

Moreover, to reduce the energy spread at the target, an energy defining slit was introduced in the magnet system. Therefore, an aluminum slit was introduced at the exit pole face of the first magnet, where large dispersion of beam was observed. The aluminum slit was specifically used to minimize the bremsstrahlung production.

Overall, the variation in magnetic filed as a function of distance along the radius of curvature in the median plane for the optimized system is shown in Fig. 5. It is observed that at the 1396, 2878 and 4677 A-turn, the optimized design produces 3324, 6221 and 9317 Gauss of magnetic field to bend the electron beam of energy 6, 12, and 18 MeV respectively.

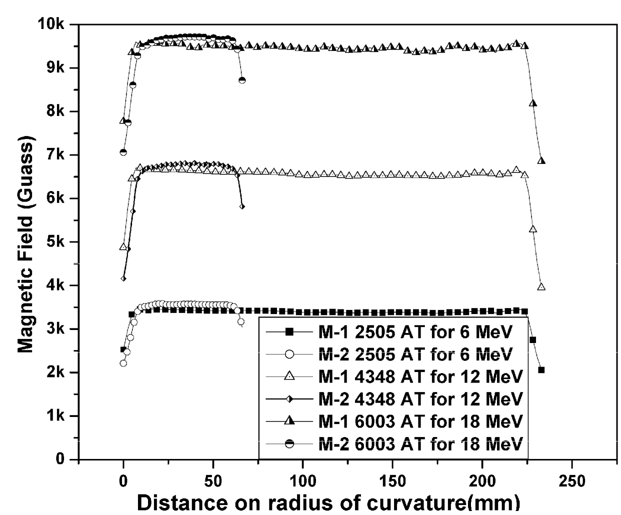


Figure 5: Magnetic field Vs distance along the radius of curvature on the median-plane for first and second magnet.

For a typical case study, a beam of energy 12 MeV, beam diameter 3 mm and energy spread of ± 7 % has been passed through the optimized design of the two magnet system. The trajectory of an electron beam is shown in Fig. 6. It is observed that the convergence angle due to first magnet has



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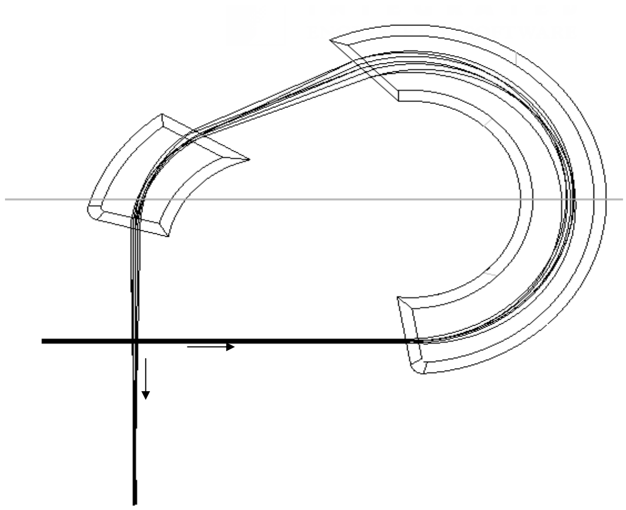

Figure 6: Trajectory of 12 MeV electron beam in two magnet system.

been compensated by the divergence angle produce due to the second magnet.

Therefore, the output parameters of the optimized design of the two magnet beam bending system for medical Linac are energy spread ±3 %, divergence angle ∼ 2.8 mrad and spot size 2.6 ± 0.05 mm. The optimized parameter for two magnet system is given in Table 2:

Table 2: Optimized Parameter of the Two Magnet System

| | |
|---|---|
| Beam Particles | Electrons |
| Operating Beam Energy | 6 to 18 MeV |
| Energy Variation | ± 3 % |
| Beam Current (Average) | ∼ 80 $\mu$Amp |
| Input Beam Diameter | ∼ 3 mm, ≤ 7 mrad |
| Output beam spot size | ∼ 2.6 ± 0.05 mm |
| Output beam divergence | ∼ 2.8 mrad |
| Main Chamber | 30.4 × 35 × 25 $cm^3$ |
| Magnet Type | Two Pole (C-shaped) |
| Magnet material | Steel 12L14 |
| Pole gap | 10 ± 0.1 mm |
| Radius of curvature | 64 mm ± 1 mm |

## CONCLUSION

The optimized design of two magnet system gives uniform distribution of magnetic field and extracts 6 to 18 MeV electron beam energy spread 3 %, divergence angle ∼ 2.8 mrad and spot size 2.6 mm ± 0.05 mm. This system is useful for the radiation therapy.

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