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A Magnet System with Reduced Gap Size for Beam Scanning

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Abstract

A magnet system with reduced gap size for beam scanning is presented. In the beam delivery system, the displacement of the beam center position at the second scanning magnet is reduced by setting the first one where betatron oscillation phase difference is 180 degrees between them. In this system , the gap size of the second scanning magnet is reduced from 45 mm to 30 mm when its length is 300 mm and deflecting angle is about 60 mrad to irradiate a 200 mm×200 mm region.

1 Introduction

In recent years, proton therapy , which has good characteristics of dose localization, has been successfully applied to cancer treatments . Usually, treatments require large uniform radiation fields, as large as 200 mm×200 mm. Since the size of the beam which is extracted from an accelerator is small, it is required to spread the beam.

To obtain such large uniform radiation fields, various beam delivery systems have been developed and are categorized by passive and active beam delivery systems[1].

Passive beam delivery systems employ single or double scatterers to spread the beam and flatten the beam intensity. And the lateral part of the spread beam is cut off by the collimator along the shape of tumor.

In active beam delivery systems, two scanning magnets are placed in tandem with their magnetic field directions orthogonal to one another and to the beam direction in order to irradiate2-dimensional regions.

In these beam delivery systems, there are two typical irradiation systems. One of them is the wobbler scatterer system[2] which uses the beam spread out by the scatterer. And the other is the spot beam scanning system[3] which uses the small sized beam($\phi\sim 10$ mm) .

At the second scanning magnet of these beam scanning systems, it needs wide gapsize in order to pass the beam deflected by the first one. And electric power consumed at the second scanning magnet becomes large.

Then, we present a new magnet systems using beam scanning system to reduce the gap size of the second scanning magnet.

2 Scheme of beam scanning to reduce the gap size

The scheme of beam scanning using the scanning magnets with reduced gap size is as follows . (i)The first scanning magnet S1 and the second one S2 are installed where the phase difference of the betatron oscillations in the deflected plane between them is 180 degrees. (ii) The first scanning magnet S1 is placed at the position upstream to the last bending magnet BM3 of the gantry. The beam is deflected in deflecting plane of bending magnets of the gantry to keep the gap size of BM3 small. (iii) The second scanning magnet S2 is placed at the position downstream to BM3 and deflects the beam in the direction vertical to the deflecting plane of bending magnets of the gantry.

If these two scanning magnets are set as (i), the position of S2 becomes the node of the deflection by the scanning magnet S1. And then, the beam deflected by S1 where X=0 returns to

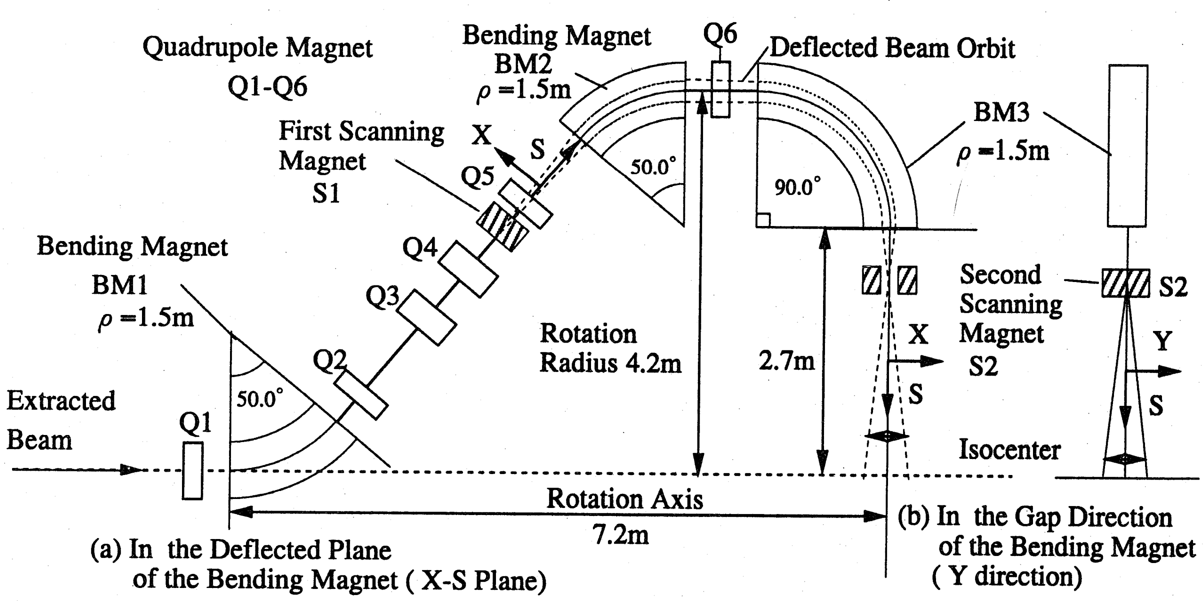

Fig. 1 An Example of the Present Scanning Magnet System

X=0 at S2.

Figure 1 shows an example of the magnet system to which the present scheme is applied. In this system, the coordinates are as follows. S is the length along the beam design trajectory. X is the position in the magnetic midplane of the gantry bending magnet. Y is orthogonal to S and X coordinates.

If the length of the second scanning magnet is L, and the maximum deflected angle by the first scanning magnet in the second one is θ, the maximum beam displacement is $L\theta/2$ in the second one. If two scanning magnets are placed in tandem, the maximum beam displacement is larger than $L\theta$. Thus, this scheme reduces the gap size of the second scanning magnet and its electronic power.

Furthermore, because there is only one scanning magnet between the last bending magnet and isocenter, rotational radius can be shorter than the gantry in which the two scanning magnets are put in tandem downstream of the last bending magnet.

3 Application of the present scheme

An optics of the gantry has been designed on condition that the extracted proton beam from a synchrotron has characteristics as shown in Table 1. The beam extracted from synchrotron has small emmitance[4]. The beam energy is 70-250 MeV. The size of the radiation field is 200 mm×200 mm. The needed deflection gradient is about 60 mrad.

Table 1. Beam parameters

Unnormalized Emittance (Horizontal, Vertical)	~3 π mm mrad
Beam Energy	70 - 250 MeV
Momentum Spread	below±0.2%
Magnetic Rigidity	1.23 - 2.43 Tm
Size of Radiation Field	200 mm×200 mm

The extracted beam from the accelerator is transported to the gantry. The gantry has three bending and six quadrupole magnets. Bending magnets are 50 degrees upward and downward ones and a 90 degrees downward one. Radius of bending magnets is 1.5 m, rotating radius is 4.2m. The maximum magnetic field of the bending magnets is 1.6 T.

Optics conditions are set in order to obtain approximately the same sizes in X and Y directions when the gantry is rotated. Optics design conditions are (i) $\beta_X=\beta_Y=$ 4-5 m and $\alpha_X=\alpha_Y=0$ at the isocenter to make a spot beam, (ii) dispersion functions and their gradients $\eta_X=\eta_X'=0, \eta_Y=\eta_Y'=0$ at the entrance of the gantry, and (iii) $\eta_X=\eta_X'=0$ at the exit of BM3.

Figure 2 shows betatron functions of the gantry to which the present scheme is applied. Both β_X and β_Y are small in the gantry beam transport system. Since the half beam size of the Y direction of the gantry is below 6 mm, the 20 mm gap size is sufficient to pass the beam in the gantry bending magnet.

Figure 3 shows dispersion functions of this gantry. The gantry optics is doubly achromatic at entrance of the gantry and the exit of the bending magnet BM3, then beam sizes of X and Y direction at the isocenter become nearly equal.

Figure 4 shows betatron oscillation phase in the deflected plane of the bending magnet. The first scanning magnet S1 is installed at the position between quadrupole magnets Q4 and Q5. It is found that the difference of the phases of the betatron oscillations is 180 degrees. To create an uniform radiation field as large as 200 mm×200 mm, the scanning width is set to be ±110 mm at the isocenter. It needs 57 mrad deflection on the first scanning magnet. If the scanning magnet length is 300 mm, it needs 0.46 T to deflect the beam.

At the second scanning magnet, the maximum scanning width by the first scanning magnet is ±9 mm and half beam size is ±4 mm. Taking the clearance into consideration, the

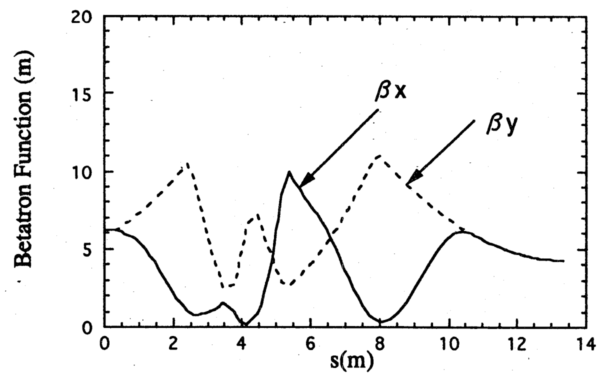

Fig. 2 Betatron functions of the Gantry

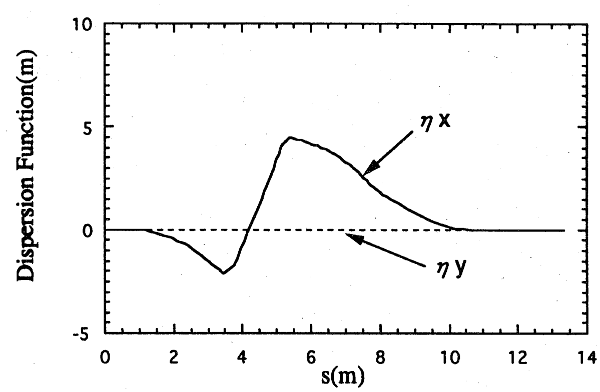

Fig. 3 Dispersion functions of the Gantry

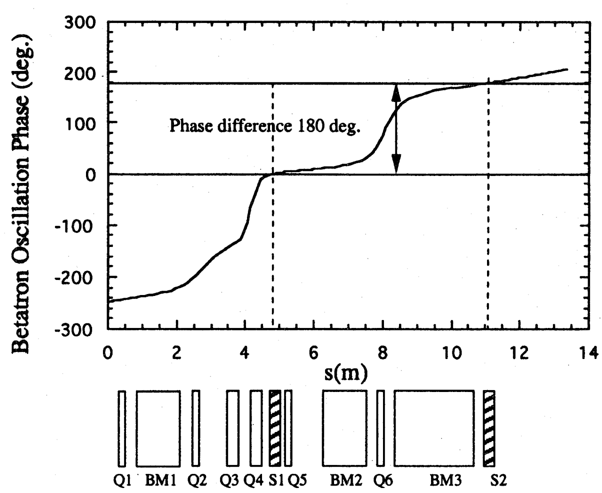

Fig. 4 Betatron Oscilation Phase in the Deflected Plane

gap size of the second scanning magnet becomes about 30mm.If we set the two scanning magnets adjacent at the position downstream to the last bending magnet, the gap size of the second scanning magnet is needed about 45 mm.

This system is also effective to reduce the rotating radius of the gantry because two scanning magnets are placed separately upstream and downstream of the last gantry bending magnet. Then, this magnet system can save the space between the last bending magnet and isocenter.

4 Summary

We presented a new beam scanning magnet system. This system is useful to reduce the gap size of the second scanning magnet and reduce the electric power consumed by it.

Applying this system to a rotating gantry, it is possible to reduce its rotating radius because two scanning magnets could be placed separately upstream and downstream of the last bending magnet of the gantry . And this scanning system would save the space to install the gantry in the treatment room.

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