CONCEPTUAL DESIGN OF A HIGH TEMPERATURE SUPERCONDUCTING SPECTROSCOPY-TYPE GANTRY SYSTEM

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Abstract

Radiation therapy is a kind of extremely efficient cancer treatment that uses high doses of radiation to kill cancer cells. In radiation therapy with high energy particles, the dose is usually applied to the tumor with irradiation from several directions, to limit the dose in healthy tissue in vicinity of the tumor. In order to realize a continuous angular range of irradiation, a spectroscopy-type beam delivery device (i.e. the gantry) is proposed. In the conception of spectroscopy-type gantry, beam is guided to the appropriate azimuthal angle with cylindrical magnetic field surrounding the patient, and treatment angles are set by adjusting magnetic strength, instead of rotating a gantry with magnets of the beam transport around the patient. With this conception as well as high temperature superconducting materials, continuous angular range of irradiation could be realized by a super compact spectroscopy-type gantry. In this work, a conceptual design of a high temperature superconducting spectroscopy-type gantry system will be present.

INTRODUCTION

Particle therapy has been used for more than a century for both curative and palliative treatments. In the last 20 years, it has undergone impressive technological development. The feature of particle therapy is to utilize the dose concentration with Bragg peak. By irradiating the lesion location with the aligned Bragg peak, the dose concentration is focused on the lesion leading to minimal side effect on the surrounding healthy tissues. Therefore, compared with traditional radiation therapy can lead to fewer side effects and patients can expect a higher quality of life after treatment.

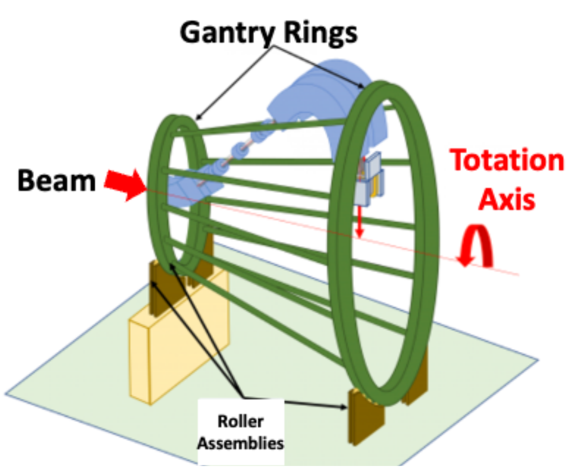

Figure 1: In a traditional gantry system, magnets are mounted in gantry rings and rotated with roller assemblies to acquire planned treatment angles.

However, as illustrated in Fig. 1, in a traditional gantry system, magnets are mounted in the gantry structure and rotated with large mechanic arm, making it too huge for many facilities to introduce. The large dimensions (8-12m diameter) and masses (100-200 tons) of the proton gantries [1] limit the rotational speed to 1 turn/min for safety measures preventing possible collisions [2]. Besides, the mechanical system in traditional gantry system restricts the available treatment angles to several preinstalled ones, which may limit treatment planning in some cases.

Therefore, to realize the compactness of gantry system, as well as continuous treatment angles for a better dose distribution, we are designing a High Temperature Superconducting Spectroscopy-type (HTSS) Gantry System.

THE HTSS GANTRY SYSTEM

The concept of a HTSS Gantry System is illustrated in Fig. 2. The key point is that treatment angles are set by controlling magnetic field, instead of rotating the whole magnet.

This idea makes it possible to realize compactness and simple mechanics, because no rotating systems are required any more. Besides, beam for treatment will be transported in an arc around the patient, making it possible to realize a continuous treatment angle range. With high temperature superconducting material, the whole system is expected to be super compact.

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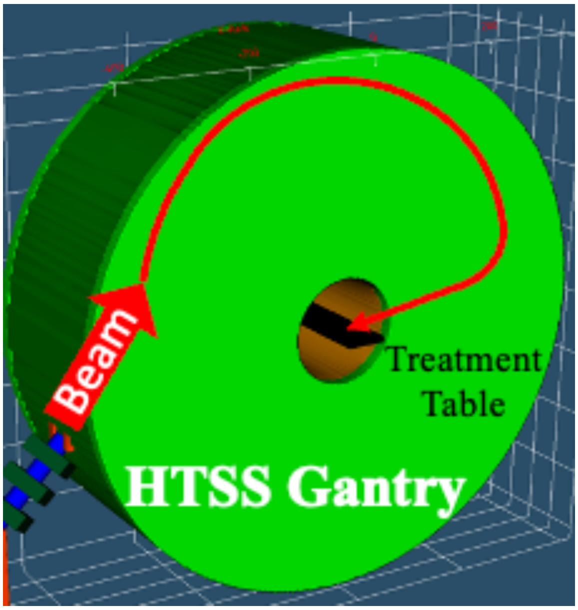

Figure 2: The concept of a HTSS Gantry System. Beam is injected from the left side and transported to treatment table in the center by internal magnetic field. The treatment angle is set by controlling the magnet field.

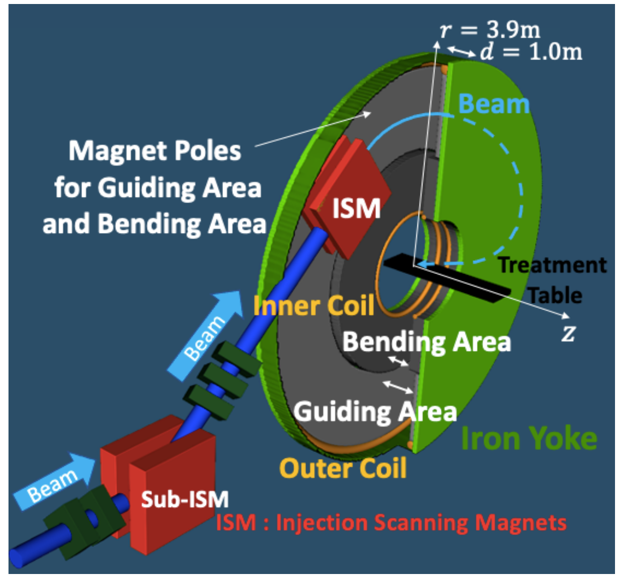

Figure 3: Designed structure of the HTSS Gantry System. Magnets poles for guiding area and bending area are illustrated in light gray and dark gray. Treatment area is within the range of inner coils, where is magnetic field free. Injection Scanning Magnets (ISM) are installed in the HTSS Gantry System.

CONCEPTUAL DESIGN

Structure of The HTSS Gantry System

The structure of HTSS Gantry System is illustrated in Fig. 3. Beam is transported in 3 steps which are guiding, bending and concentrating. Firstly, beam will be transported to planned direction in guiding area, then bended towards the treatment table in bending area and finally concentrated for treatment in treatment area. Both of magnet fields in guiding area and bending area is excited by outer coils with the help of properly adjusted pole gaps G in each field, given by Eq. (1).

$$\frac{H_{Guiding}}{H_{Bending}} \approx \frac{2G_{Gduing}}{2G_{Bending}} \qquad (1)$$

The magnetic field in treatment area is cancelled by inner coils. During a treatment, the internal magnetic field is designed to be a static one, and the treatment angle is set by controlling Injection Scanning Magnet (ISM) which is a dipole magnet installed in the HTSS Gantry System. ISM bends the beam and inject it onto specifically designed orbit in the gantry. Because the internal magnetic field keeps static during a treatment, we can calculate the particle orbits for any treatment angle with simulated internal magnetic field profile.

Internal Magnetic Field Profile

Figure 4 shows the simulated magnetic field profile in z direction, defined in Fig. 3, as a function of radius in the midplane, when the exciting current is $2I = 3.88 \times 10^5$ [A · turns] for outer coils, and $2I = -2.67 \times 10^5$ [A · turns] for inner coils.

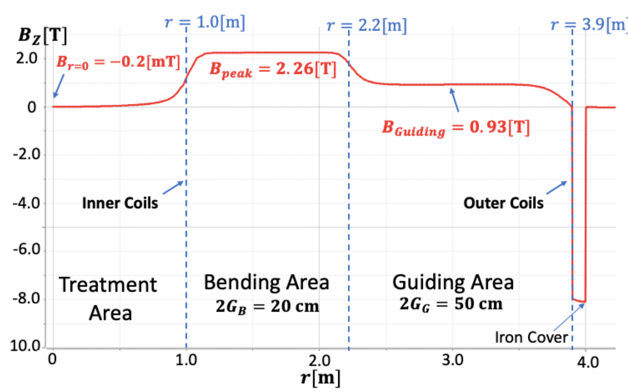

Figure 4: Magnetic field profile in the midplane simulated by OPREA. The peak of B_z in bending area is about 2.26[T]. In guiding area, B_z keeps at about 0.93[T]

With the result of $B_z(r)$ in Fig. 4, the transport matrix $\mathcal{M}$ for single particle can be calculated with Eq. (2).

$$\mathcal{M} = \begin{pmatrix} 1 & l & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cos(\sqrt{\kappa}z) & \frac{1}{\sqrt{\kappa}}\sin(\sqrt{\kappa}z) \\ 0 & 0 & \frac{d}{dt}\cos(\sqrt{\kappa}z) & \frac{d}{dz}\frac{1}{\sqrt{\kappa}}sin(\sqrt{\kappa}z) \end{pmatrix} \quad (2)$$

where l is the transporting length, κ the radius of orbit in the magnetic field, z the transporting direction of particles.

Transport matrix for particle beam, which requires considering beam dynamics, will be designed in the next phase. Therefore, here we only calculated elements affecting single particle in the midplane. Using the transport matrix $\mathcal{M}$, we can now calculate the particle orbit in the gantry system for desired treatment angles with numerical calculation.

Particle Orbit

Figure 5 shows calculated particle orbits in the midplane of the HTSS Gantry System, for treatment angle θ from 0° (vertical treatment) to 180° (vertical treatment from the back), with a changing step of 10°, using 230 MeV protons, the maximum energy typically used in proton therapy, with the magnetic field profile $B_z(r)$

When the beam is transported to ISM, we need to control the magnetic field in ISM to inject beam to the gantry system, satisfying the injection data (r_0, φ_0) for required treatment angle, at the exit of ISM, where r_0 is the distance from the center, and φ_0 is the angle between particle direction and normal direction of the exit of the ISM.

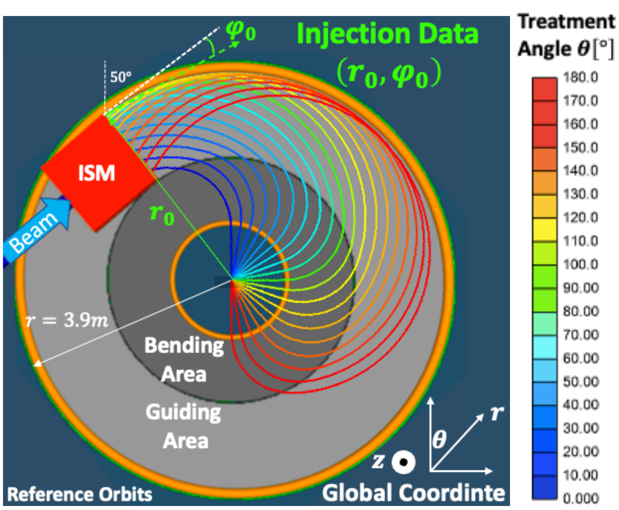

Figure 5: Particle orbits in the midplane of the HTSS Gantry System, using numerical calculation.

With the result of particle orbits, we can now sum up and make a graph of injection data (r_0, φ_0) for each treatment angle θ (Fig. 6). The balls on the curve in Fig. 6 present

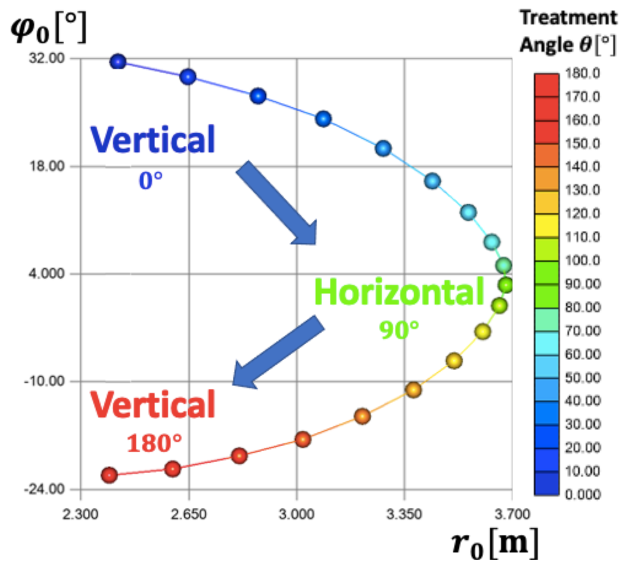

Figure 6: Injection data (r_0, φ_0) for treatment angle 0°~180°.

the injection data for each treatment angle with a changing step of 10°, but the treatment angles between steps are also valid, which means the whole curve gives the injection data for continuous treatment angle in the range of 0°~180°. In this design, ISM is installed in the Guiding Area, giving a restriction $2.3\text{m} < r_0 < 3.7\text{m}$, which is the width of the Guiding Area. And the restriction of φ_0 will be discussed in the next phase, which mainly depends on the performance of ISM.

SUMMARY

In order to realize compactness and a continuous treatment angle of gantry system for particle therapy, we are developing a High Temperature Superconducting Spectroscopy-type (HTSS) Gantry System. Here we have presented a potential possibility for a gantry with a radius of 4m to realize continuous treatment angles in a range of 180°.

In the next phase, we will study on how to satisfy the injection data with ISM, and the beam dynamics in the gantry. Besides, how to deal with the beam energy changing for different depth of tumor is also an issue for next phase. Keep the current magnetic field and calculate injection data for beam energy changing. Otherwise, use the current particle orbits and change the magnetic field strength in the gantry, which needs to consider the hysteresis of Fe pole.

REFERENCE

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[2] Nicolini G, Clivio A, Cozzi L, Fogliata A and Vanetti E, 2011, On the impact of dose rate variation upon RapidArc implementation of volumetric modulated arc therapy, *Med. Phys.*, 38 264-71.