DESIGN OF SUPERCONDUCTING ROTATING-GANTRY FOR HEAVY-ION THERAPY

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Abstract

We are designing a superconducting rotating-gantry for heavy-ion therapy. This isocentric rotating-gantry can transport heavy ions having 430 MeV/u to the isocenter with irradiation angles over 0-360 degrees. For the magnets, combined-function superconducting-magnets will be employed. The use of these superconducting magnets allowed us to design the compact rotating gantry; the length and radius of the gantry would be approximately 13 m and 5.45 m, respectively, which are comparable to those for the existing proton gantries. We report the design for our superconducting rotating-gantry.

INTRODUCTION

Tumor therapy using energetic carbon ions, as provided by the HIMAC, has been performed since June 1994, and more than 6000 patients were treated until now. With the successful clinical results over more than 17 years, we constructed a new treatment facility. The new facility would have three treatment rooms; two of them have both horizontal and vertical fixed-irradiation-ports, and the other has a rotating-gantry-port[1]. For all the ports, a scanning-irradiation method is applied. The fixed-irradiation-ports were constructed and commissioned [2], and we are now designing the isocentric rotating gantry.

The rotating gantry is an attractive tool in the ion radiotherapy, because a treatment beam can be directed to a target from any of medically desirable directions, while a patient is kept in position. This flexibility of the beam delivery for this type of the gantry, isocentric gantry, is advantageous to treat tumors having wide range of tumor sites and sizes, and hence the requirements of having the rotating gantry would increase for hospital-based therapy complexes, which will be constructed in near future.

The rotating-gantry, which we are designing, can transport heavy ions having 430 MeV/u to the isocenter with irradiation angles over 0-360 degrees. For the magnets of the gantry beam-line, combined-function superconducting-sector-magnets will be employed. In this paper, the design of the rotating gantry, including a layout and beam optics as well as results of 3D electromagnetic calculations for the superconducting magnets, will be presented.

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GANTRY LAYOUT AND BEAM OPTICS

A three-dimensional image of the isocentric rotating-gantry for the new treatment facility is presented in Figure 1. The rotating gantry has the truss structure with the two large rings on the both ends. The end rings supports the entire structure, and are placed on the turning roller to rotate along the central axis over 0-360 degrees. The carbon beam, as accelerated with the upper ring of the HIMAC, is transported with ten sector-bending-magnets, which mounted on the gantry structure through each of their supporting structure, and directed on a target at the isocenter. In the treatment room, a tumour of a patient is precisely positioned with a robotic couch.

Figure 2 shows a schematic drawing of the gantry beam line, as installed in the rotating part of the gantry. The beam line consisted of ten sector-bending-magnets (BM1-10), a pair of scanning magnets (SCM-X and SCM-Y), and three pairs of steering magnets and beam profile-monitors (STR1-3 and PRN1-3). To design the compact gantry, the superconducting combined-function sector-bending-magnets would be employed. With quadrupole field in those bending magnets, the beam can be focused without any quadrupole magnet.

The beta and dispersion functions are shown in Figure 3. The quadrupole fields of the bending-magnets for each of BM1-3 and BM4-6 would provide D-F-D focusing.

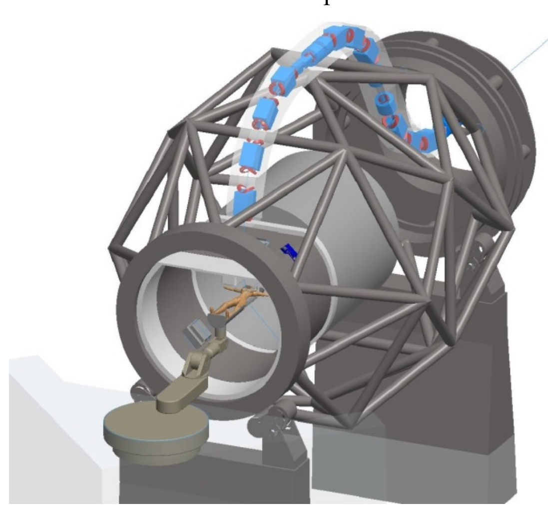

Figure 1: Three dimensional image of the rotating gantry.

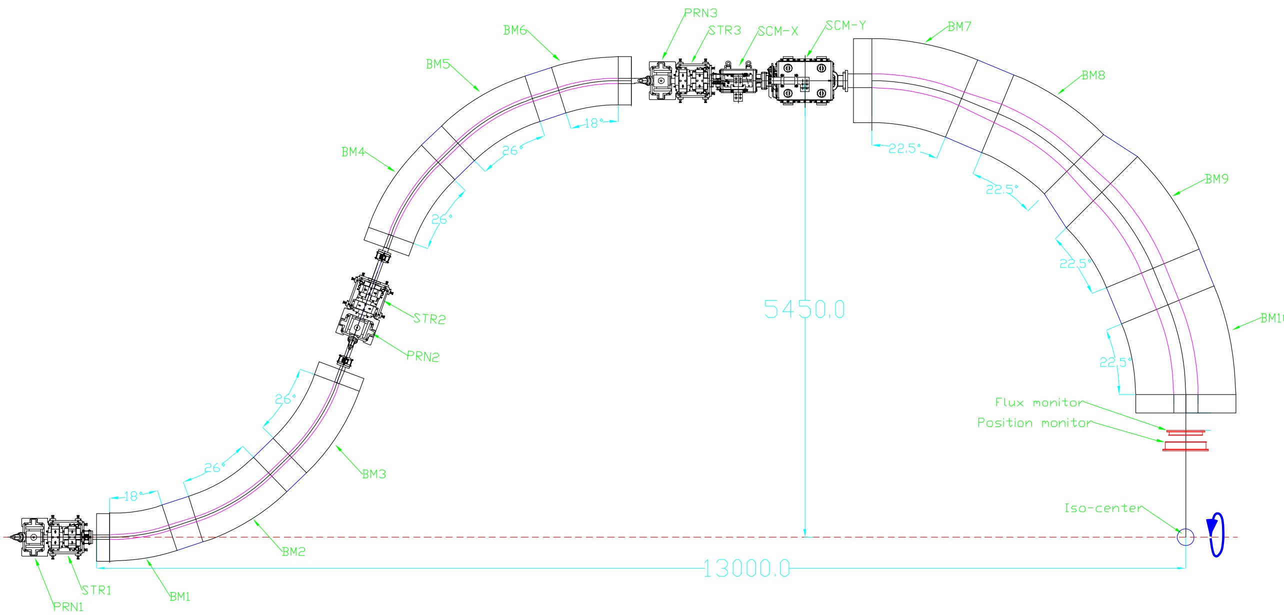

Figure 2: Schematic drawing of the rotating gantry for the heavy-ion therapy.

The four sector-bending-magnets, BM7-10, were consecutively aligned downstream of the scanning magnets. Since scanned beams traverse BM7 through BM10, the beam trajectory of the beams has to be taken into account to determine the bending radius and angle of BM7-10. As a small value of the bending radius is taken, a radius and length of the rotating gantry would be reduced, however the scanned beam would concurrently have strong radial focusing from the sector-bending-magnet. As a compromise between the sizes of the irradiation field and gantry structure, the bending radius of 2.8 m was chosen for BM7-10. Further, to overcome the radial focusing, the quadrupole coils were installed for BM9 and BM10, so that the equal sizes of the irradiation field between horizontal and vertical coordinates were

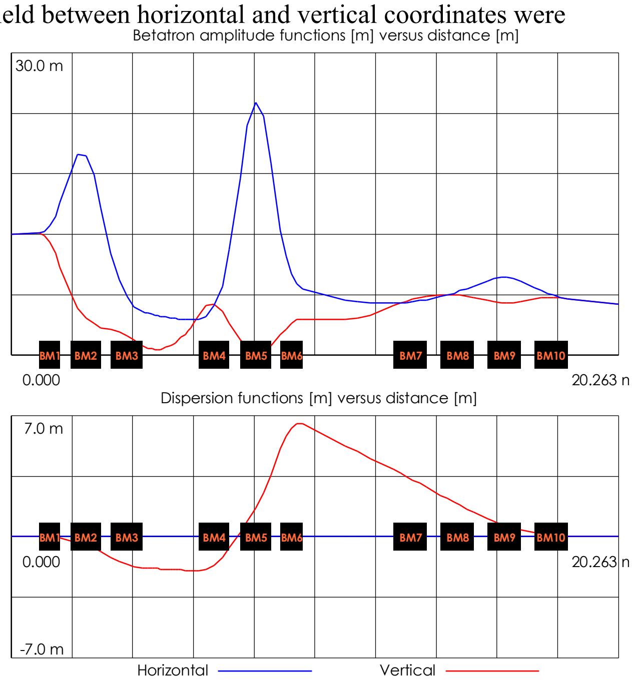

Figure 3: Beta and dispersion functions.

obtained at the isocenter as shown in Figure 4. The maximum scan size at the isocenter is 188mm×188mm with the kick angles of 18 mrad and 21 mrad for SCM-X and SCM-Y, respectively.

SUPERCONDUCTING MAGNETS

Major parameters of the superconducting magnets, as used in the gantry beam-line, are summarized in Table 1. All of these superconducting magnets have the surface-winding coil-structure. Due to the limited pages, we will present the magnet design for BM1-6.

A cross-sectional view for BM1-6 is presented in Figure 5. The diameter of the beam duct is 60 mm, and the duct is surrounded by thermal insulators. The superconducting quadrupole coil consisted of eight superconductor layers,

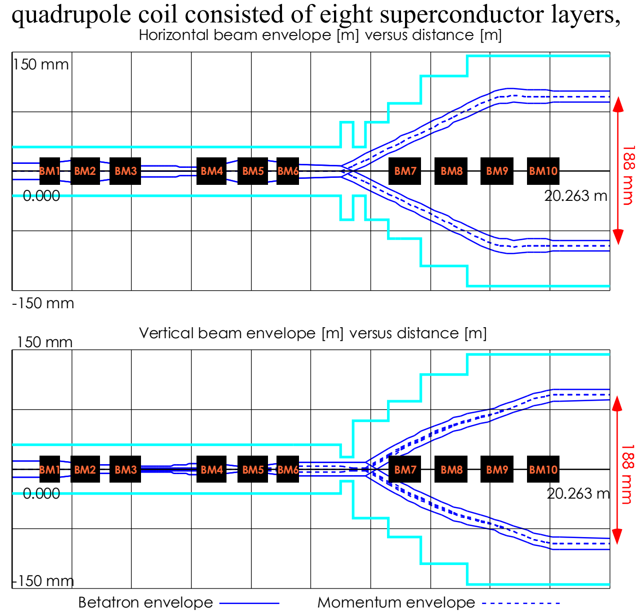

Figure 4: Beam envelope functions with kicks of the scanning magnets, located between BM6 and BM7.

Table 1: Summary of Specification for the Superconducting Magnets Used in the Gantry Beam Line

Parameter	Symbol	BM1/BM6	BM2-5	BM7	BM8	BM9/BM10	Units
Bending angle	θ	18	26	22.5	22.5	22.5	deg
Bending radius	ρ	2.3	2.3	2.8	2.8	2.8	m
Bore radius	R_0	30	30	85	120	145	mm
Reference radius	r_0	20	20	60	80	100	mm
Maximum field	B_{max}	2.88	2.88	2.37	2.37	2.37	T
Maximum field gradient	G_{max}	10	10	—	—	1.3	T/m
Uniformity (dipole)	$\Delta BL/BL$	$\pm1\times10^{-4}$					—
Uniformity (quadrupole)	$\Delta GL/GL$	$\pm1\times10^{-3}$					—

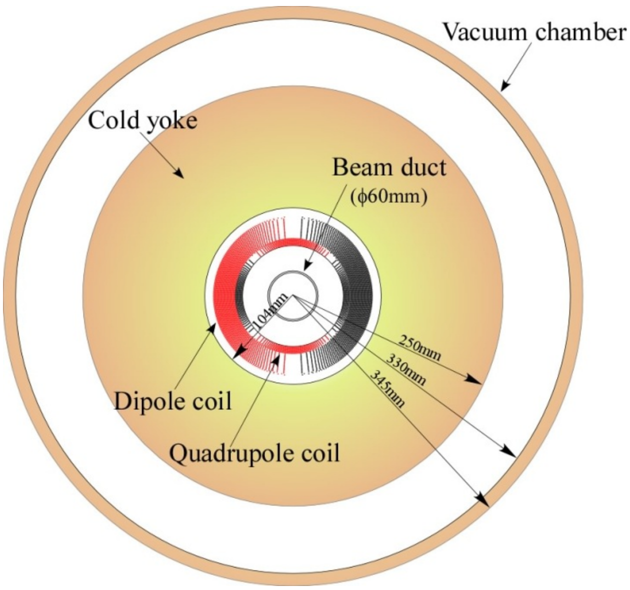

Figure 5: Cross sectional view of the superconducting magnet for BM1 through BM6.

and they are wounded on the coil base. Outside of the quadrupole coil, the twenty-six layers of the superconducting dipole-coil would be stacked. Totally, the thirty-four layers of the superconductors would be installed inside of the cold yoke.

The 3D-electromagnetic field calculations using the Opera 3D code were performed[3]. In the calculations,

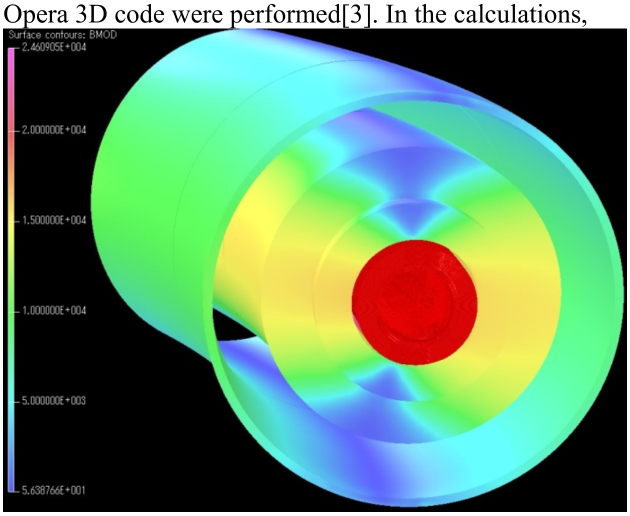

Figure 6: Result of 3D electromagnetic field calculation using the Opera3D code. A unit of the color map in Gauss.

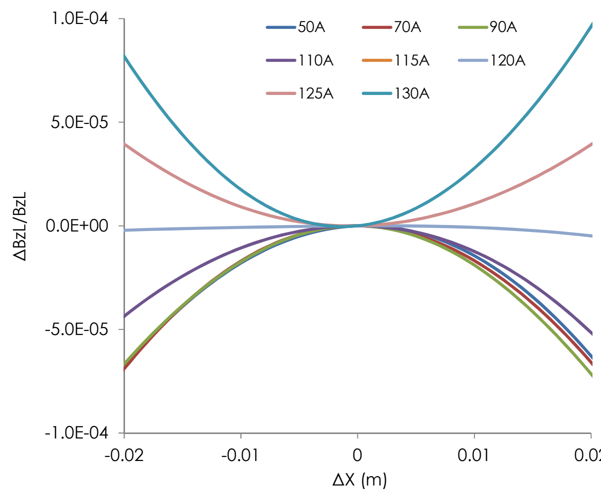

Figure 7: Uniformity of dipole field, $\Delta B_zL/B_zL$, for the various coil currents. The calculated B_zL was 3.03 Tm with the coil current of 130 A.,

the dipole and quadrupole superconductors of 3614 and 422 turns/pole were precisely modelled. The calculated field is shown in Figure 6. Having optimized positions of the superconductors, we obtained the uniformity of the dipole field, $\Delta B_zL/B_zL$, as shown in Figure 7. The same optimization procedure has been performed for the quadrupole, and we obtained the uniformity of the field gradient for the quadrupole to be better than $|\Delta GL/GL|=2\times10^{-4}$.

SUMMARY AND CONCLUSION

We are designing the superconducting rotating-gantry for the heavy-ion therapy. Having employed the superconducting combined-function magnets, we could design the compact gantry; the length and radius are approximately 13 m and 5.45 m, respectively. The 3D electromagnetic calculations were performed, and we obtained the field uniformity, as expected. We will construct the two superconducting magnets, BM2 and BM10, by the end of this fiscal year.

REFERENCES

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[2] T. Furukawa, *et al*, Med. Phys. 37 (2010) 5672.
[3] Opera Version 14R1, http://www.cobham.com/.