# PRESENT STATUS OF A SUPERCONDUCTING ROTATING-GANTRY FOR CARBON THERAPY

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*Abstract*

A superconducting rotating-gantry for carbon therapy is being developed. This isocentric rotating gantry can transport carbon ions with the maximum energy of 430 MeV/u to an isocenter with irradiation angles of over ±180 degrees, and is further capable of performing three-dimensional raster-scanning irradiation. The combined-function superconducting magnets were employed for the rotating gantry. The superconducting magnets with optimized beam optics allowed a compact gantry design with a large scan size at the isocenter; the length and the radius of the gantry are approximately 13 and 5.5 m, respectively, which are comparable to those for the existing proton gantries. A construction and installation of the superconducting gantry is in progress, and beam commissioning will begin from this autumn. We will report an overview as well as a present status of the superconducting rotating-gantry.

## INTRODUCTION

In recent years, an application of high-energy particle accelerators to cancer therapy has attracted many attentions, and a number of medical particle accelerators were constructed around the world. In the ion radiotherapy, the rotating gantry is a very attractive tool, because a treatment beam can be directed to a target from any of medically desirable directions, while a patient is kept in the best position. This flexibility of the beam delivery for this type of the gantry, *isocentric rotating gantry*, is advantageous to treat tumors having wide range of tumor sites and sizes.

For proton cancer therapy, rotating gantries were commonly constructed around the world. However, it would be very difficult to construct a rotating gantry for carbon therapy, because the required magnetic rigidity for carbon beams having energy of 430 MeV/u is roughly three times higher than that for proton beams having energy of 250 MeV/u, and hence the size and weight for the gantry structure, including magnets and its counterweight, would become considerably larger. To overcome this problem, a superconducting rotating gantry for carbon therapy is being developed [1]. The construction as well as installation of the superconducting gantry is in progress, and beam commissioning will begin from this autumn. In this paper, an overview as well as a present status of the gantry is presented.

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## OVERVIEW OF THE GANTRY

Figure 1 shows a three-dimensional image of the superconducting rotating gantry. This rotating gantry has a cylindrical structure with two large rings at both ends. The end rings support the total weight of the entire structure, and are placed on turning rollers so as to rotate the beam line on the rotating gantry along the central axis over ±180 degrees. Carbon beams, provided by the HIMAC, are transported with ten sector-bending superconducting magnets, mounted on the gantry structure through each of their supporting structures; they are directed on a target located at the isocenter

Figure 2 shows a schematic drawing of the beam line, installed in the rotating part of the gantry. The beam line consists of ten sector-bending superconducting magnets (BM01-10), a pair of scanning magnets (SCM-X and SCM-Y), and three pairs of steering magnets as well as a beam profile monitor (STR01-03 and PRN01-03). To design the compact gantry, combined-function superconducting magnets are employed except for BM07 and BM08. These superconducting magnets have a surface-winding coil structure, and can provide both dipole and quadrupole fields.

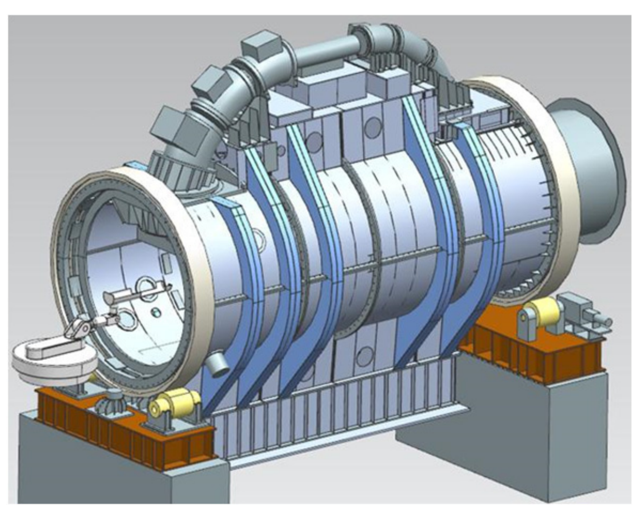

Figure 1: Schematic drawing of the superconducting rotating gantry.




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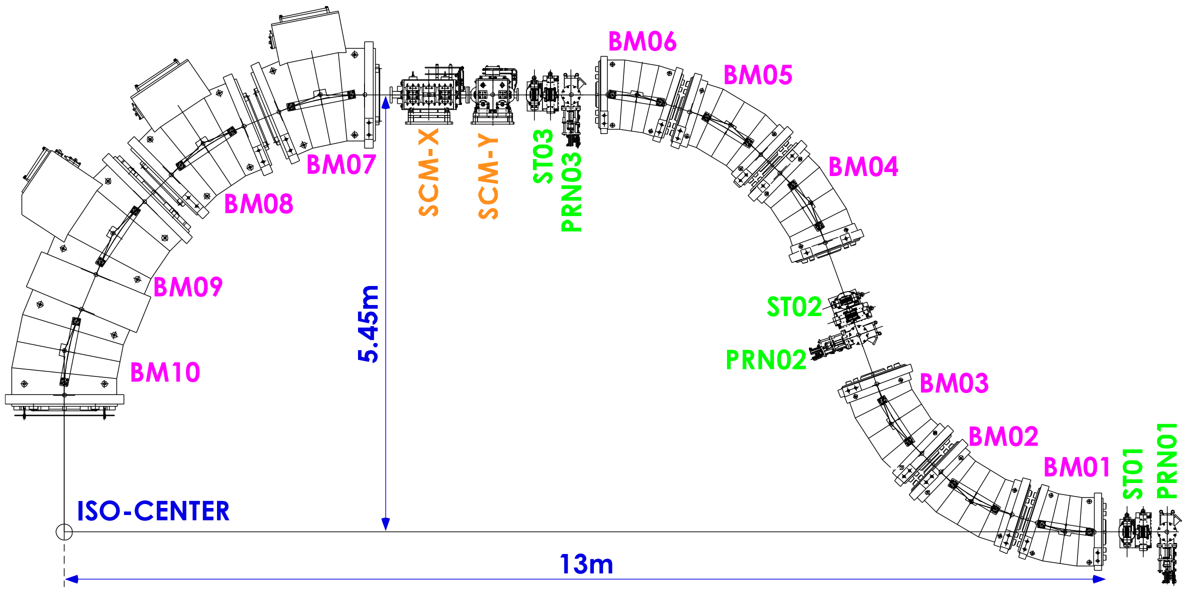


Figure 2: Layout of the superconducting rotating gantry. The gantry consists of ten superconducting magnets (BM01-10), a pair of the scanning magnets (SCM-X and SCM-Y), and three pairs of beam profile-monitor and steering magnets (ST01-03 and PRN01-03).

Figure 3 shows the beta and dispersion functions along the beam line of the rotating gantry. The blue and red curves in Fig. 3 represent those for the horizontal and vertical coordinates, respectively. The twiss parameters at the entrance of the gantry is $\beta_x=\beta_y=30$ m, $\alpha_x=\alpha_y=0$, $D_x=D_y=0$ m, $D'_x= D'_y=0$, while the twiss parameters for the isocenter is designed to be $\beta_x=\beta_y=1$ m, $\alpha_x=\alpha_y=0$, $D_x=D_y=0$ m, $D'_x= D'_y=0$. Since a typical 2σ beam emittance for energy of 430 MeV/u is $\varepsilon\sim1$ πmm·mrad, the beam size at the isocenter is $\sqrt{\beta\varepsilon}\sim1$ mm.

All of the superconducting magnets were designed using the “Opera-3d” code [2]. A result of the calculation for BM02-05 is presented in Fig. 4. The positions of the superconducting wires were optimized so as to provide uniform magnetic field over the effective aperture of ϕ40 mm for BM02-05. With the calculated magnetic fields for all the superconducting magnets, beam-tracking simulations were made. The simulation results agreed well with those of the linear beam-optics calculation, proving validity of the final design for the superconducting magnets [3].

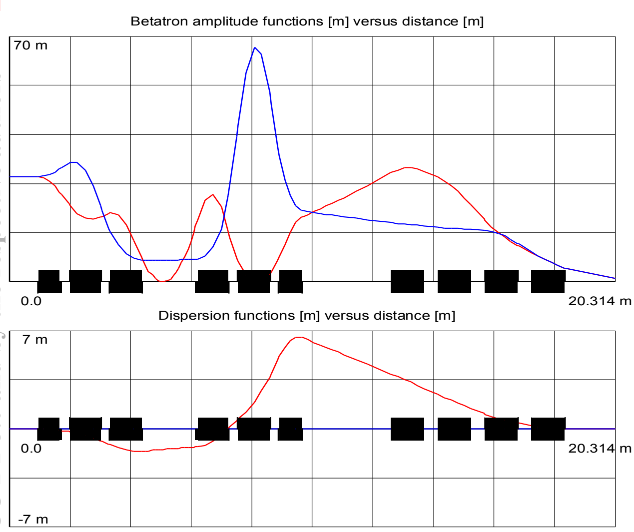


Figure 3: Beta and dispersion functions along the gantry beam line.

## CONSTRUCTION AND INSTALLATION

Having completed the design, all the superconducting magnets were constructed, and field measurements using Hall probes as well as NMR probes were performed. The measured field map over the magnet aperture agreed with that, calculated by the “Opera-3d” code, although we observed quadrupole field, originated from the dipole coil [4]. However, since the magnets have the dipole and quadrupole coils, this quadrupole field from the dipole coil can be corrected by adding or reducing coil current from the designed quadrupole coil current.

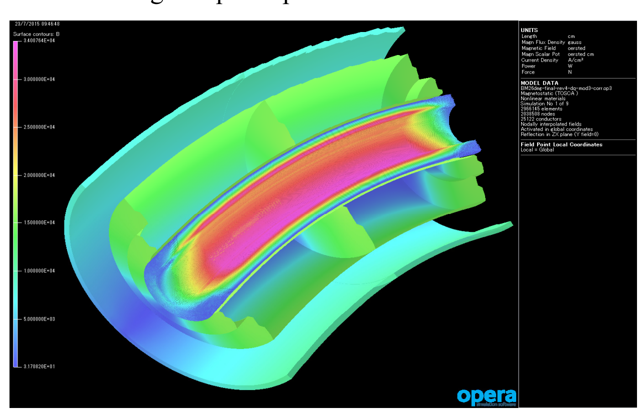


Figure 4: Result of three-dimensional field calculations for BM02-05 using the “Opera-3d” code.



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Figure 5: Rotation tests of the gantry structure at the Toshiba Keihin Product Operations.

The gantry structure was designed to have a cylindrical shape with the two large rings at both ends as shown in Fig. 1. The length between the two end rings is approximately 14 m, and the outer diameter of the end rings is 6.5 m. In the design, the detailed FEM calculations were performed, and the gantry structure was optimized so as to minimize deformation of the structure, as caused by rotating the entire structure of the gantry. Finally, the maximum displacement of the each superconducting magnet was estimated by the calculations to be less than 1 mm.

Because of the construction and transportation issues, the cylindrical structure of the rotating gantry was divided into eight large parts. The eight parts as well as the two end rigs were made at the Toshiba Keihin Product Operations. At Toshiba, the gantry structure was assembled with dummy weights, instead of the magnets, and rotation tests were performed as shown in Fig. 5. The deformation was precisely measured by a laser tracker, and we found that measured deformations roughly agreed with those predicted by the FEM calculations.

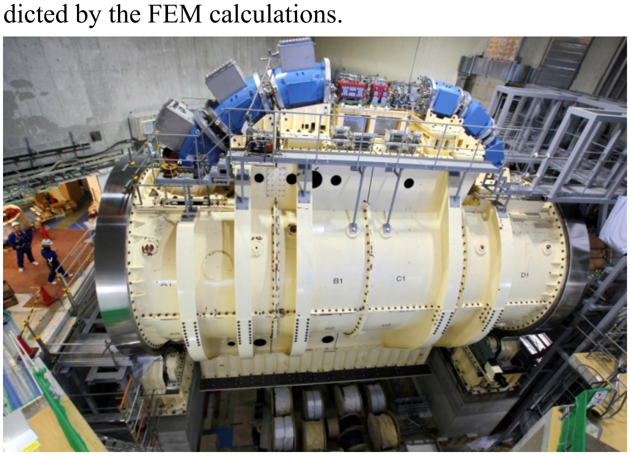

Figure 6: Picture of the superconducting rotating-gantry, as installed in NIRS. All the magnets as well as the profile monitors were mounted on the gantry structure.

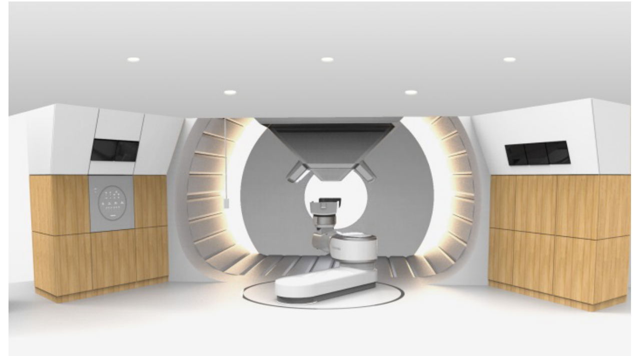

Figure 7: Image of the treatment room for the rotating gantry.

Having made a series of the tests at Toshiba, the rotating gantry was disassembled into the parts, and they were transported to the gantry room in NIRS. Then, the parts were installed and reassembled in the gantry room, and further the superconducting magnets as well as all the other beam transport devices were mounted on the gantry structure as presented in Fig. 6. Having activated cryocoolers, all the superconducting magnets were now cooled down below 4 K.

A design image of the treatment room is given in Fig. 7, and its construction is in progress. All the construction is planned to be completed by the end of September.

## SUMMARY

A superconducting rotating-gantry for carbon therapy is being developed. By using the combined function superconducting magnets, the size and weight of the gantry structure is considerably reduced. After finalizing the construction of the treatment room, we will begin beam commissioning from this autumn.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] Y. Iwata et al., “Design of a superconducting rotating gantry for heavy-ion therapy”, Phys. Rev. ST Accel. Beams. 15, 044701 (2012).

[2] “Opera-3d” software, http://www.cobham.com/.

[3] Y. Iwata et al., “Development of a superconducting rotating-gantry for heavy-ion therapy”, Nucl. Instrum. and Meth. in Phys. Res. B 317, 793 (2013).

[4] Y. Iwata et al., “Development of curved combined-function superconducting-magnets for a heavy-ion rotating-gantry”, IEEE Trans. on Appl. Supercon-ductivity, Vol. 27, Issue3, 4400505 (2014).

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