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Lightweight design of superconducting magnets for a rotating gantry with active shielding

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1. Introduction

■ In heavy particle therapy, a rotating gantry enables charged particles to be delivered to a tumor with great accuracy.

■ The superconducting magnet for the rotating gantry is composed of a cosine-theta superconducting coil surrounded with an iron yoke which is the heaviest part of the magnet's weight.

■ A superconducting magnet composed of an active shield coil for the gantry has been proposed to simplify the control system and the frame structure of the rotating gantry by reducing its weight.

■ Magnetic field design of a cosine-theta superconducting magnet with active shielding for a rotating gantry is presented.

Fig. 1 Superconducting rotating-gantry for carbon-ion radiotherapy.

2. Design concept & Requirements

(1) The inner radius of the dipole coil is fixed at 0.09 m.

(2) The dipole field is 2.37 T in the reference radius of 0.06 m.

(3) Higher multi-pole components normalized by the dipole component are less than 1.0×10^{-3}.

(4) The stray field is less than 5 G (=5.0×10^{-4} T) at a distance 0.5 m radially from the magnet center.

(5) The load factor (= operating current /critical current) of the magnet is less than 70% at 5 K.

(6) A superconducting wire for the coil winding is a NbTi wire whose diameter is 0.9 mm.

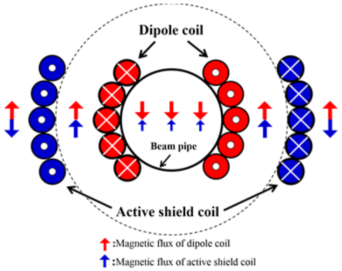

Fig. 2. Concept diagram of a dipole coil with an active shield coil.

Table 1. Parameters of a dipole coil and an active shield coil.

Coil type	Dipole	Shield
Inner R	90 mm	300 mm
Outer R	210 mm	350 mm
No. of layer	60	25
No. of turn	6954	3000
Current	217 A	249 A

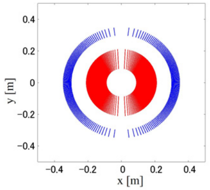

Fig. 3. Cross-section of the dipole and the active shield coils.

3. Magnetic field

■ Two-dimensional magnetic fields of the coil cross-section were calculated.

■ The peak fields of the dipole and the active shield coils are 2.40 T and 1.55 T, respectively.

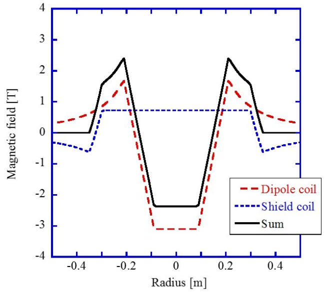

Fig. 4. Magnetic field distributions on the midplane.

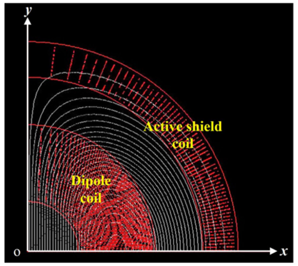

Fig. 5. Magnetic flux lines of the superconducting coil with active shielding.

4. EM force

■ Electromagnetic (EM) force per unit length occurring in the coil cross-section was calculated when the magnetic field was 2.37 T at the magnet center.

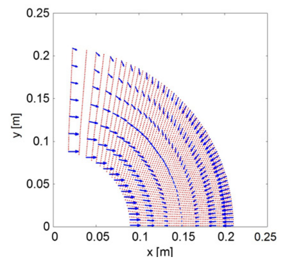

Fig.6 EM forces in a quadrant of the dipole coil.

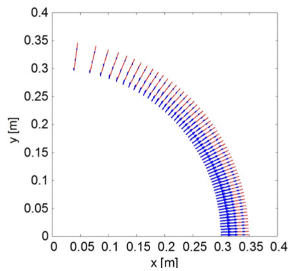

Fig.7 EM forces in a quadrant of the active shield coil.

Table 2. EM forces generated in a quadrant of the coil cross-section when the dipole field is 2.37 T at the magnet center.

	EM force in horizontal direction	EM force in vertical direction
Dipole coil	196 kN/m	-538 kN/m
Shield coil	182 kN/m	98 kN/m

5. Load line

■ The load factors of each coil are as follows: 51% in the dipole coil and 52% in the active shield coil.

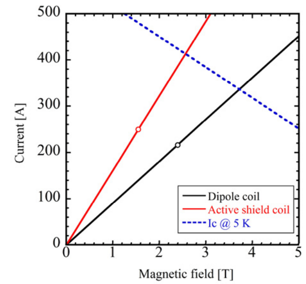

Fig. 8 Load lines of the dipole and the active shield coils.

6. Evaluation of magnet weight

■ Regarding the weight of magnets for the rotating gantry, a superconducting magnet with active shielding was compared to a superconducting magnet with an iron yoke which is being used in QST.

Table 3. Weight comparison between the magnet with active shielding and the magnet with an iron yoke.

	Magnet with active shielding	Magnet with iron yoke
Dipole coil winding	79 kg/m	28 kg/m
Shield coil winding	34 kg/m	—
Iron yoke	—	2472 kg/m
Epoxy	380 kg/m	25 kg/m
Total weight	493 kg/m	2520 kg/m

7. Conclusion

■ The design study of a superconducting magnet with active shielding for a rotating gantry was conducted in order to realize the weight reduction of the magnet.

■ It was successful to develop the coil design method of the superconducting magnet with active shielding.

■ The result of the design study indicates that the magnet weight can be reduced using an active shield coil instead of an iron yoke.

Acknowledgment

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