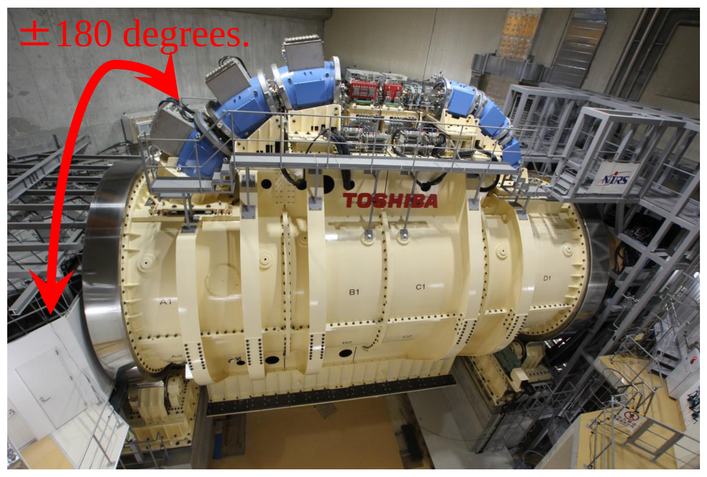
Maintenance method for stable operation of a superconducting rotating-gantry

Yasufumi Uchida[A)], Yoshiyuki Iwata[B)], Masashi Katsumata[A)], Takeo Nakajima[A)],
Tomohiro Miyoshi [A)], Hiroyuki Harada [A)], and Eiichi Takada[B)]
A) Accelerator Engineering Corp. 6-18-1-301 Konakadai, Inage-ku, Chiba-city, Japan 263-0043
B) National Institutes for Quantum and Radiological Science and Technology 4-9-1 Anagawa, Inage-ku, Chiba-city, Japan 263-8555

1. Introduction

●***NIRS outline***

At National Institute of Radiological Sciences (NIRS), carbon-ion radiotherapy has been carried out since June 1994, and more than 10,000 patients were treated by now. Recently, the world's first superconducting rotating-gantry was developed, and further installed in the new treatment facility at NIRS.



●***Superconducting rotating-gantry***

This gantry equips ten superconducting magnets, and can transport carbon ions to an isocenter over irradiation angles of between ±180 degrees.

For cooling of the superconducting coil in the magnet, cryocoolers are employed; each magnet has three or four cold heads of cryocoolers, and totally thirty-four cryocoolers were employed for the ten superconducting magnets.

●***Cryocooler***

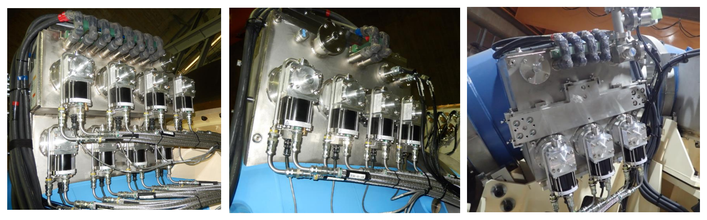
(GM_cryocooler RDK-415D)

This system is liquid helium-free.

Cooling capacity changes up to about 10% by mounting angle.

Periodic maintenance is necessary.

Cold heads:every 10,000 hours



TypeA ***TypeB*** ***TypeC***

Fig. 1 superconducting rotating-gantry and cryocoolers

TypeA : Two magnets are cooled with 8 cryocoolers
TypeB : One magnet is cooled with 4 cryocoolers
TypeC : One magnet is cooled with 3 cryocoolers

In the spring of 2017, we carried out the first maintenance of all the cold heads, while conducting the beam commissioning of the gantry before treatment operation starts. Having replaced and maintained all the cold heads, the superconducting gantry is now in clinical use since May 2017.

In this presentation, we will introduce the maintenance method for stable operation of the cryogenic system for the superconducting gantry.

2. Method of exchange

Normally, maintenance of the cryocooler is performed during half-yearly shut down period. However, maintenance of the cryocooler generally requires a period of one month or more due to temperature rise and re-cooling. Therefore, it is impossible to complete the maintenance at half-yearly shut down period. So we performed the "cold maintenance"; the cold heads, as mounted in the magnet, were replaced while minimizing temperature increase.

The figures below show the actual time when cold maintenance was performed. The maintenance for the 4set of cryocooler can be made within 1.5days.

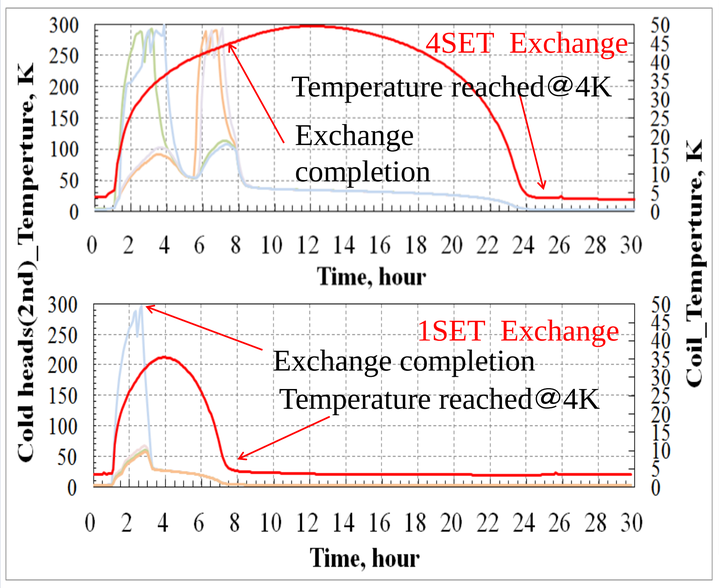
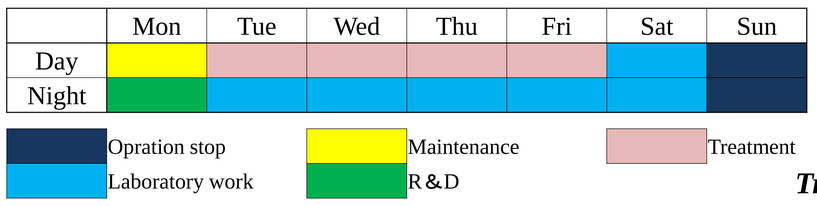


Fig. 2 Temperature trend when cold maintenance was performed

		Maintenance time,Hour	
		1SET	3SET or 4SET
Preparation		2 - 6.5	
Vacuum Drawing		1	
Exchange Cold head		2	6
Vacuum Drawing	Cooling time	7	17
Tidying-up			
Training		1.5	
Total time		13.5 -18	27.5 - 34

Table 1 Time table of the cold maintenance

In case of a failure of cryocooler, we can perform maintenance to recover the designed cooling power at weekend.



※Half-yearly shut down
August : 1 month
March : 2 weeks

Treatment schedule for NIRS

3. Early detection of failure

In order to operate the superconducting rotating gantry steadily, we need to find a failure at an early stage. We found that the precursor of the cryocooler can be found by check the coil temp at the gantry angle of 0 deg.

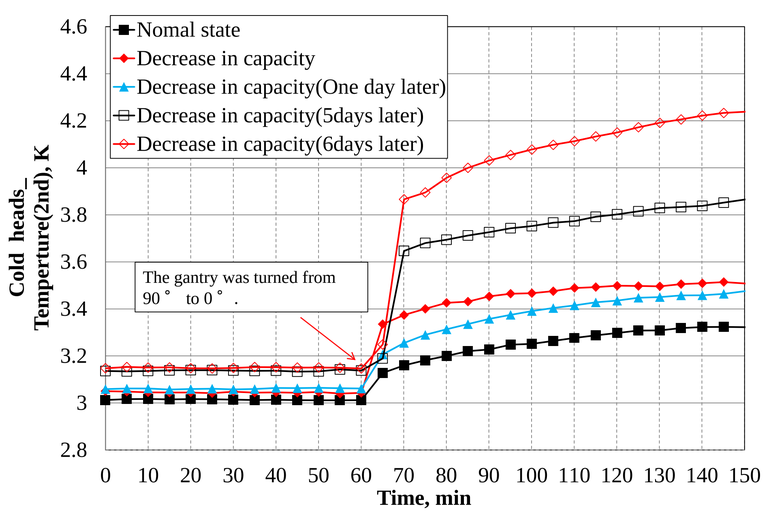


Fig.3 Temperature trend data taken 6 days

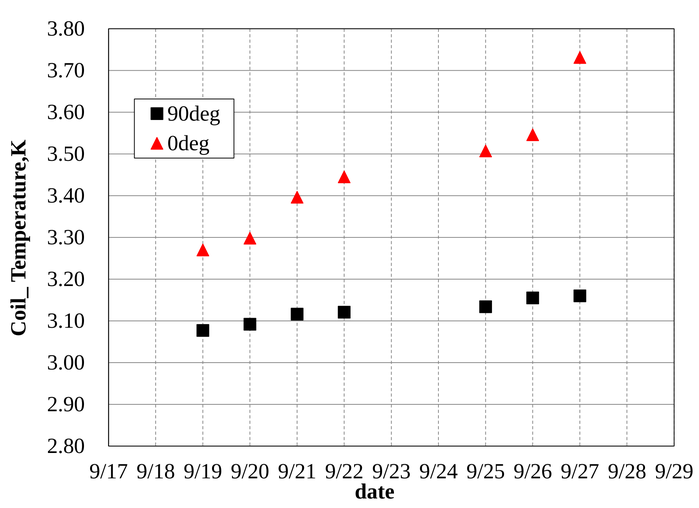


Fig. 4 Daily coil temperature data

We found the method to detect the precursor of failure cryocooler.

4. Robustness

The superconducting rotating gantry of NIRS is designed so that the superconducting magnets can be operated even if one cryocooler per magnet stops.The figures below show the temperature data when one cryocooler per magnet is stopped at gantry angle of 0 deg.

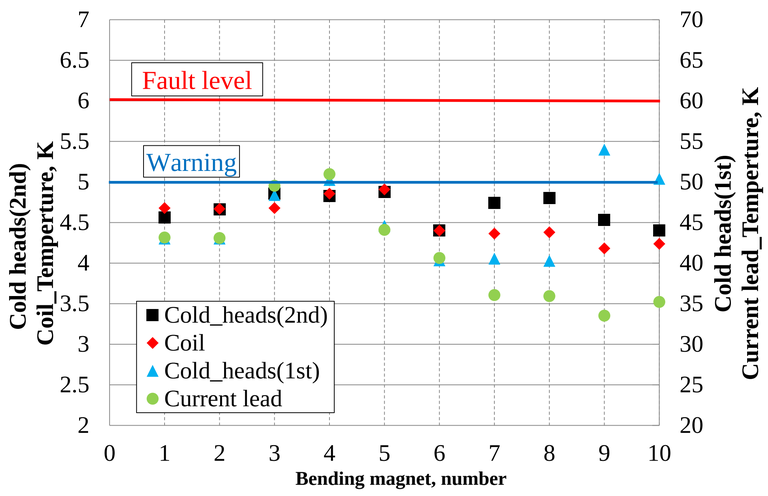


Fig. 5 Temperature data when one cryocooler per magnet is stopped

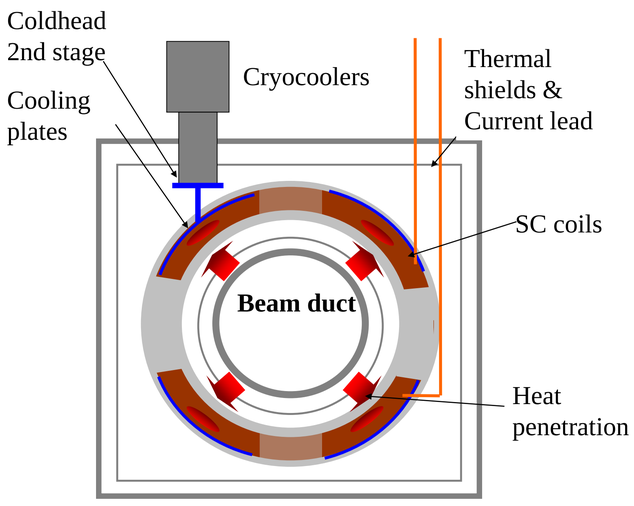


Fig. 6 Schematic view of superconducting magnets

※Two magnets of BM09 and BM10 are cooled with eight one cryocoolers.
Depending on the combination, the temperature will rise to fault level.

We confirmed that the superconducting magnets can operate even if one cryocooler stopped.

GM_cryocooler RDK-415D has different cooling capacity depending on mounting angle.

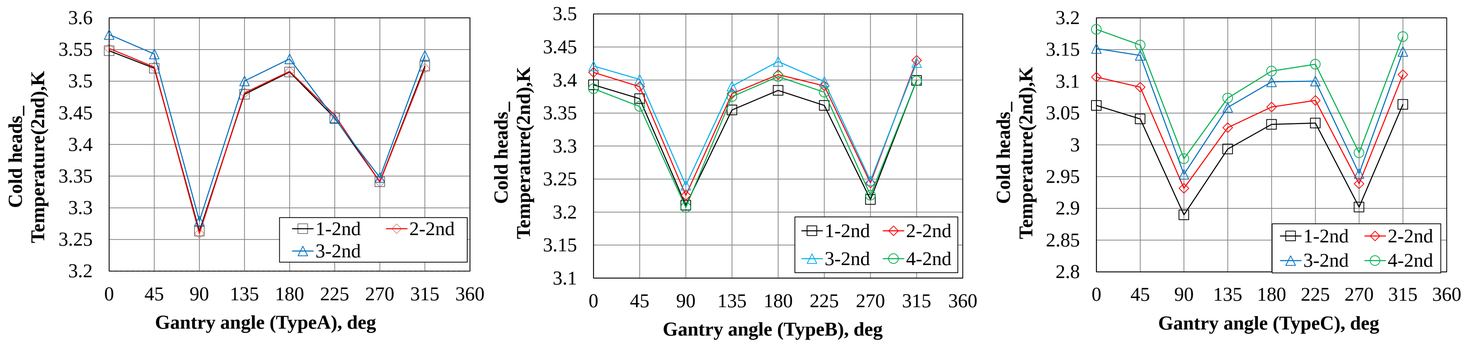


Fig. 7 The cryocooler temperature for each gantry angle

This cryocooler has poor cooling capacity at a gantry angle of 0deg and 180deg.

5. Maintenance cycle

We will perform maintenance as shown in Fig.8.

We are confident that we can operate without interrupting the treatment schedule by implementing the following maintenance cycle.

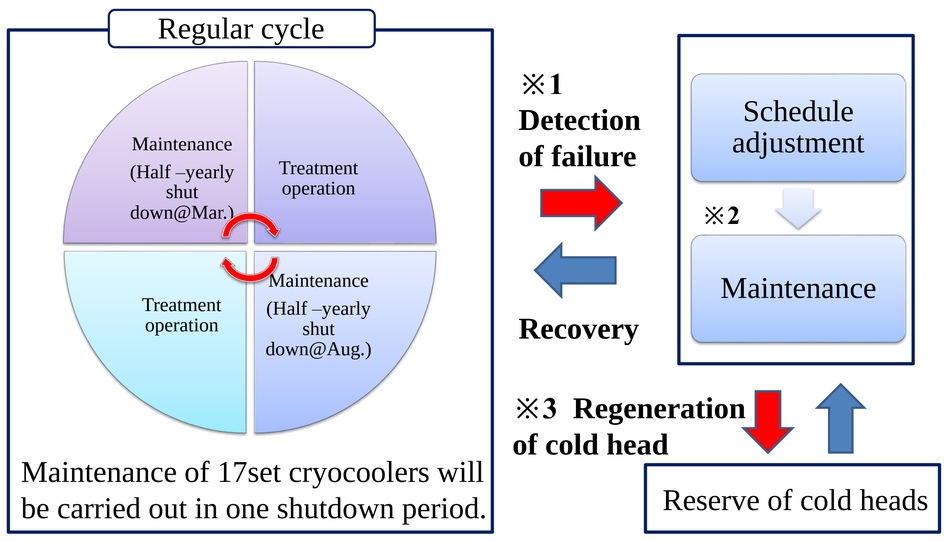


Fig. 8 Maintenance cycle

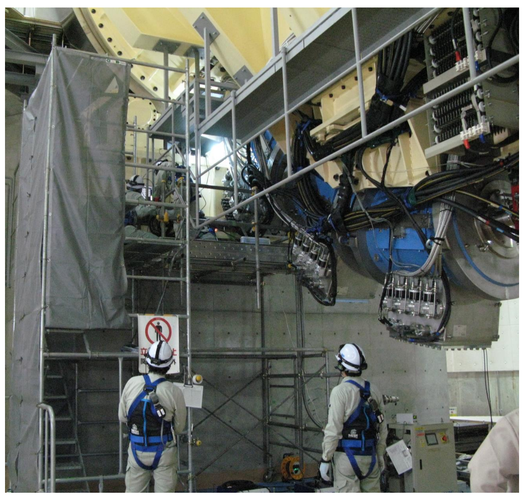


Fig. 9 Maintenance of cryocooler(gantry angle of 180deg)

※1 We have to discover the failure of the cryocooler from the gantry angle and the coil temperature.

※2 We complete maintenance on the weekend.

※3 The removed cold head is overhauled to be spare parts.

6 .Summary

●***Summary***

In the spring of 2017, we carried out the first maintenance of all the cold heads, while conducting the beam commissioning of the gantry before treatment operation starts. So the superconducting rotating-gantry is now in clinical use since May 2017.

From the experience we have maintained, we have established a method for early detection of failure and an early recovery method. By implementing this maintenance method, we convinced that long-term stable operate will be possible.

● ***Future plans***

Improving the efficiency of the maintenance work of the cryocooler. We will be ready to complete maintenance work even at midnight on weekdays.

Increasing the maintenance cycle by stopping one cryocooler in the middle of the night.