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STABILIZATION OF CYCLOTRON MAGNETIC FIELD STRENGTH BY MEANS OF MAGNET TEMPERATURE CONTROL

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Abstract

Magnetic field strength of a cyclotron drifts by the order of 10^{-4} due to change in temperature of the magnet of several degrees, which causes beam intensity decrease with time. We analysed the data of the magnet temperature and the magnetic field of the JAERI AVF cyclotron and made heat conduction simulation with a computer code. It has turned out as a result that the main heat sources are the main coil and the trim coils. The cooling system of the coils was modified to terminate or reduce the heat conduction to the yoke and the poles. Consequently, the temperature increase of the magnet has been reduced to one tenth, or 0.5°C, and the beam intensity has turned satisfactorily steady.

1 INTRODUCTION

It is known for many cyclotrons in the world that beam intensity gradually decreases when they are operated at a high magnetic field. Since the start of the cyclotron routine operation at JAERI in 1991, we have experienced a strong decrease of beam intensity for several tens of hours after the cyclotron was excited at the main coil current higher than 500 A. In the typical case of 195 MeV $^{36}Ar^{8+}$ acceleration at 820 A (1.6 T average magnetic field), beam currents went down to zero in ten hours. The acceleration phase of internal beam drifted as well. The operators had to adjust current of the outermost trim coil every few hours in order to recover the beam intensity by enhancing the average magnetic field.

This recovery process clearly shows that decrease in the magnetic field strength gave rise to the beam intensity decrease. On the other hand, the reason why the magnetic field decreased was unknown for a long time. We accumulated the data of magnetic field strength of the cyclotron and temperature of the cyclotron magnet yoke for more than two years. A clear correlation was found between the magnetic field strength and the temperature. The preliminary results of the measurement was reported at the last symposium [1]. We further carried out thermal conduction simulation by using the thermal analysis code "NASTRAN" [2] in order to confirm the origination of the magnetic field drift and to design a device for stabilization.

According to the results of the measurement and the simulation, we decided to modify the cooling system for the coils to control the magnet temperature in order to stabilize the magnetic field.

The stabilization will provide us with great advantages in use of acceleration or irradiation techniques as well as in beam intensity stability. For example, in addition to the beam decrease, we observed that single-pulse beams, formed after two-hour tuning of the cyclotron and the chopping system, spread out to multi-pulse beams in twenty minutes. The stabilization will realize steady single-pulse beams. Furthermore, the cocktail beam acceleration of M/Q=2 and 4 requires high stability of the magnetic field strength to keep low ratio of impurity ions.

In the following sections, the results of the measurement and the simulation, the outline of the stabilisation system, the results of stability tests with the system are described.

2 MEASUREMENT AND HEAT CONDUCTION SIMULATION

Temperature of the yoke surface was measured at more than 30 points. We used platinum resistance thermometers at the points near the main coil where magnetic field was strong and C-C thermocouples at the other points. An NMR probe was put on a hill at about 800 mm radius where uniformity of the magnetic field was good enough to catch NMR signals. However, the noise due to RF or mechanical vibration of a signal cable often disturbed the measurement in spite of our efforts to reduce the noise. The measurement of temperature and magnetic field was carried out on various beam acceleration conditions for more than two years.

Figure 1 shows an example of the data for 50 hours after the main coil was excited at 820 A. The side of the upper pole which is closest to the main coil in the figure has the fastest rise and the highest value of temperature. The sudden changes in magnetic field at 8, 13 and 47 hours were given by tune of the outermost trim coil current for beam intensity recovery. Behaviour of the change of magnetic field and temperature appears very similar. The relaxation time of them are 30 to 50 hours for the temperature and 40 hours for the magnetic field. The data strongly suggests that decrease in the magnetic field was caused by change in the magnet temperature and the primary heat source was the main coil.

The thermal simulation with NASTRAN was made using an actual dimension of the cyclotron magnet. The parameters such as the thermal conductivity between the main coil and the yoke surface were chosen so that the calculation results agreed satisfactorily with the measurement. Heat transfer from the main coil to the pole side was ignored because evaluation of transfer through the 5 mm gap was very difficult.

Figure 2-a is an example of the calculation which shows temperature distribution after 50 hours. The initial yoke temperature is 25°C, the highest temperatures of the main coil and the trim coil is 50°C and 38.1°C, respectively. In the figure, the temperature is highest in the area facing the main coil and the trim coil #11, which consume the largest power of the 12 pairs of the trim coils. This result clearly illustrate the heat conduction from the main coil and the trim coil to the yoke, the pole and the side yoke. It appears that we can understand most of the data by taking these coils as the main heat source.

In the calculation for Fig. 2-b, a plate of 25°C was inserted for heat insulation and the trim coil temperature was set at 25 °C. The figure shows the typical increase of the temperature decreased from 5°C to 0.5°C.

The simulation has clarified that the combined use of the heat insulation and lowering temperature of the trim coil is effective. The stabilisation device was designed to control the yoke temperature with these ways.

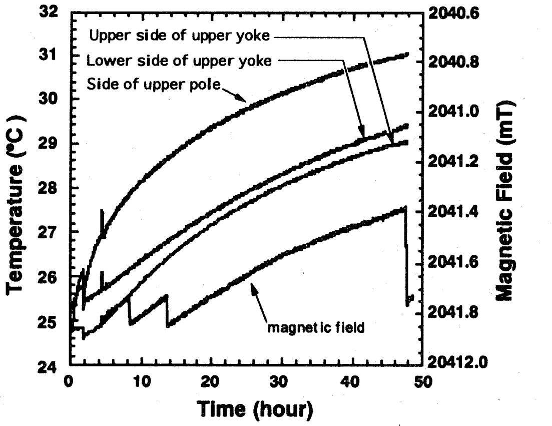

Fig. 1 Time dependence of the yoke temperature and the magnetic field strength at 820 A main coil current.

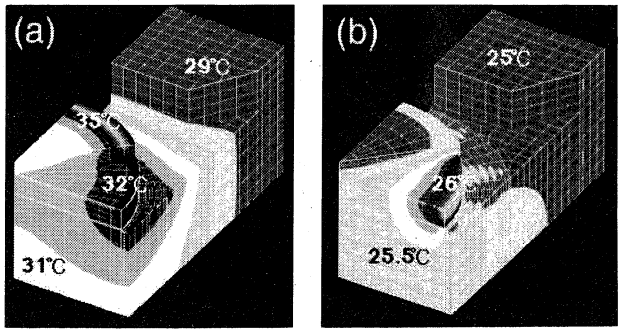

Fig.2 Temperature distribution of the magnet surface after 50 hours. A 1/4 part of the lower yoke and the pole is shown. Note that color scale is different between (a) and (b). See the text for the detail of the calculation condition.

3 OUTLINE OF TEMPERATURE CONTROL SYSTEM

The temperature control system was designed to reduce the temperature rise over the whole yoke less than 0.5°C 50 hours after excitation of the cyclotron magnet start. It consists of following two parts.

1) Thermal insulation between the main coil and the yoke by inserting temperature-controlled copper plates. The temperature of the plates is kept constant around 25°C by water circulation in the hollow conductors embedded in them.
2) Temperature control of coolant for the trim coils to keep the average temperature of the inlet and the outlet water unchanged independently of the coil currents.

A new additional cooling unit controls three water loops independent of the existing cooling system: one is for the temperature-controlled copper plates and the others are for twelve trim coils. As the trim coil #11 generates more than 50% of the total heat of the trim coils, the trim coil water loops are divided into two loops: for the trim coil #11 and for the other eleven trim coils, respectively. In each loop, average temperatures of the inlet and the outlet water can be controlled with an accuracy of ± 0.5°C.

4 TEST OPERATION OF TEMPERATURE CONTROL SYSTEM

The beam stabilization test with the temperature control system was carried out in two ways with acceleration of 195 MeV $^{36}Ar^{8+}$. The first is to keep the coolant temperature for the copper plates and the trim coils at 24°C, the initial temperature when the cyclotron operation starts. The second is to warm the yoke at about 26°C, closer to the coil coolant of 30°C by operating the

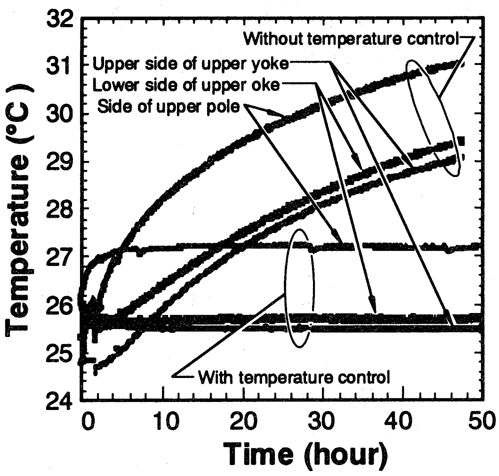

Fig. 3 Comparison of temperature change with time with and without system operation in the second way.

temperature control system while the cyclotron stops, and to lower the copper plate temperature to absorb the heat into the pole side through the gap.

As a result using the first way, the yoke temperature rose by 2 to 3°C in 50 hours, the rising rate was a half of the case without the temperature control system. The time, in which the beam intensity halved, was extended from 5 to 20 hours. The intensity decreased to 10 % of the initial intensity 40 hours after the cyclotron operation started. Although we had appreciable improvement, the temperature rise is several times as large as that designed. This indicates that influence of other minor heat sources or conduction paths such as air temperature or air gap between the main coil and the pole became relatively larger.

The second way gave us a successful improvement. The temperature rise of the yoke was less than 1°C after 50 hours. Figure 3 compares the temperature with and without the temperature control system operation in the second way.

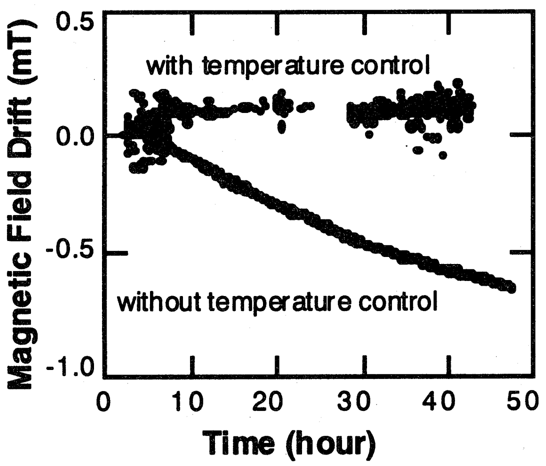

Fig.4 Magnetic field drift. Data points with temperature control are scattered because of noise for an NMR probe.

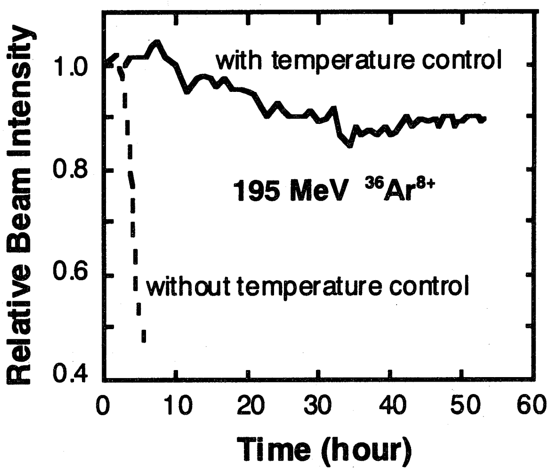

Fig. 5 Change in beam intensity with time comparing with and without system operation in the second way.

As a result, the magnetic field and the beam intensity were stabilized well as shown in Fig. 4 and Fig. 5, respectively.

5 SUMMARY

The 195 MeV $^{36}Ar^{8+}$ beam was satisfactorily stabilized using the temperature control system. To meet various acceleration condition of the cyclotron, accumulation of operation data of the temperature control system is necessary as well as more careful optimization of the system parameters.

Now that the influence of the major heat sources were substantially reduced, the heat path of gap between the main coils and the yoke has become major. In addition we sometimes observed influence of changing air temperature of the cyclotron vault. Therefore tight heat shields over a wide surface of the cyclotron yoke will be necessary for higher stability.

6 REFERENCES

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