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High Stability Operation of the RCNP Ring Cyclotron

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Abstract

In order to accelerate high quality beams, high stability of the magnetic field and the acceleration voltage are needed. The correlation between magnetic field and the temperature of the trim coils is found. to control the temperature of the cooling system for the magnetic system, the stability of the magnetic field is significantly improved. together with the highly stabilized RF system, high quality beam is accelerated stably for more than 180 hours without any adjustment of accelerator parameters.

1 Introduction

The RCNP ring cyclotron has been operated to serve various kind of high quality beams for the nuclear physics experiments. An emphasis is placed on the design to accelerate high quality beams for precise experiments. In order to realize high beam energy resolution and single turn extraction, a variable frequency flat-topping system is used[1]. Various efforts for improving the beam quality and the beam extraction efficiency have been done. The voltage fluctuations of the acceleration cavities are less than 10^{-4}. The RF phase drifts of the cavities are less than 0.1 °. The current stability of the main coils are better than 4×10^{-6} for the injector cyclotron and the ring cyclotron. The stability of the trim coils are less than 1×10^{-5}. For stability of the magnetic field, it is not sufficient to stabilize currents of the magnet. With change in temperature of the magnet, the magnetic field is drifting. Recently the correlation between magnetic field and the temperature of the trim coils is found. It is shown that the effect of the room temperature and main coil temperature can be effectively compensated with controlling the temperature of the cooling water for the trim coils. To control the temperature of the magnet, the field drift is suppressed below $\pm 1 \times 10^{-6}$/week.

2 Flat-topping system

The RF system consists of three single gap acceleration cavities and a single gap flat-topping cavity to accelerate high quality beam. The frequency range of the acceleration cavities is 30~52MHz. The frequency region of the flat-topping system is 90~156MHz, which corresponds to the third harmonic of the acceleration frequency. Fig. 1 shows an energy gain vs. rf phase with and without flat-topping. The width of the phase region where $\Delta V/V < 10^{-4}$ is 1.62 ° without flat-topping. The phase region is expanded to 15.1° with the flat-topping system, where flat-topping voltage is $-1/9V_{acc}$. As in Fig. 1 if the phase shifts 0.1° from optimum value, the energy gain increases 4×10^{-5} and the peak position shifts about 5°. For effective operation of the flat-topping system, the voltage and phase stability are very important.

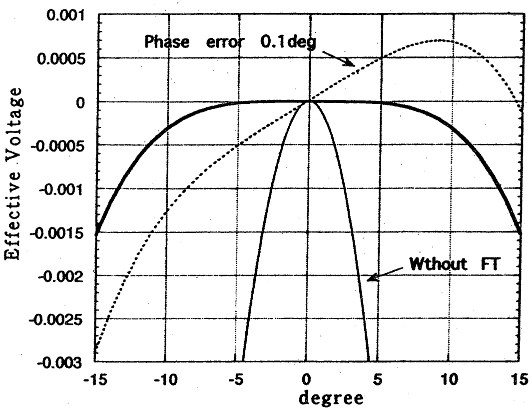

Fig. 1 Effective acceleration voltage vs. rf phase. Deceleration voltage is $1/9V_{acc}$.

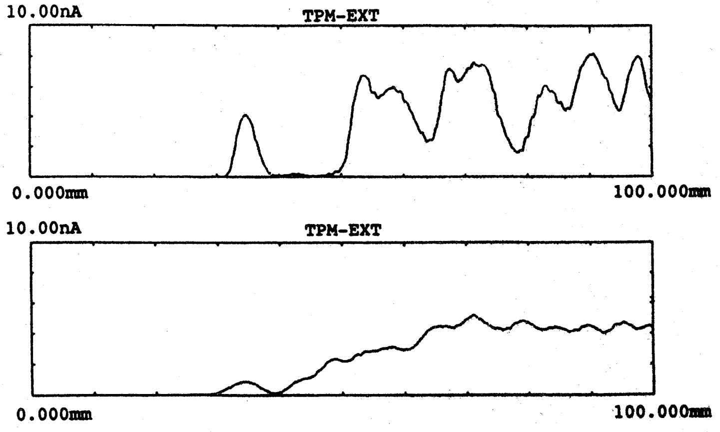

Fig. 2 Typical turn pattern of 450MeV ^3He beam at the extraction region measured by a profile monitor.
Upper: with flat-topping. Lower: without flat-topping.

The temperature of the cooling water for the cavities are controlled within 0.1° variation by a PI temperature regulator. The control circuits for the RF system are oven-controlled within 0.01° temperature drift. The filament power supplies, bias power supplies and screen grid power supplies for the RF power amplifiers are stabilized. Typical phase excursion of the cavities is less than 0.1°/week. Voltage variations are less than 0.01 and 0.05% for the acceleration and the flat-topping, respectively. Fig. 2 shows a typical turn pattern at the extraction region with and without flat-topping.

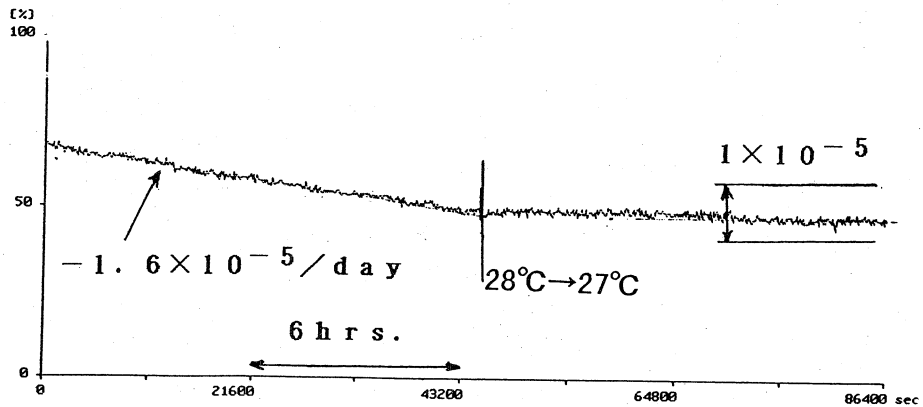

Fig. 3 Trend data of the magnetic field.

3 Stabilization of the magnetic field

Stability of the magnetic field is affected by the current of the power supply and temperature of the iron core of the magnet. The magnetic field of the sector magnets of the ring cyclotron are monitored by NMR-probes.

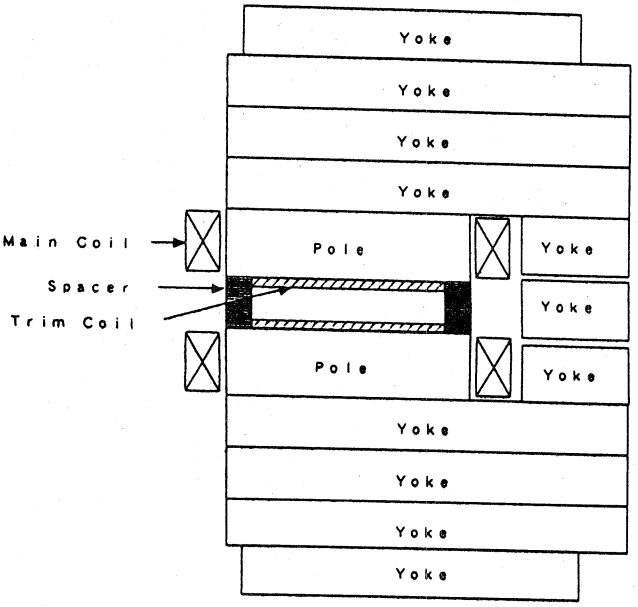

Fig. 4 The schematic view of the sector magnet for the Ring Cyclotron.

After long shut down of the cyclotron, the magnetic field usually satarts to drop with a rate of about 10^{-5}/day from start up of the ring cyclotron and after a week the field stability become better than 10^{-6}/day. The weight of the iron core of the sector magnet is 370 tons. A simplified model calculation of heat conduction for the iron core shows that if there was an initial temperature difference of 5 °, it needs more than 100 hours to reach thermal equilibrium within 0.1 °[2]. From these reason, the origin of the drift is considered to be a change in temperature of the magnet core. It was found that the temperature of the cooling water for the trim coils strongly correlates to the stability of the magnetic field. Fig. 3 shows the trend data of the magnetic field. Around thermal equilibrium, temperature change of 1° causes change in field drift of -1.6×10^{-5}/day. Effect of temperature change of the main coil or room temperature was little. Fig. 4 shows schematic view of the sector magnet for the ring cyclotron. The magnet has spacers, and magnet gap is determined by the spacers. The trim coils are made of ceramic coated copper plates. Each trim coil is mounted on the pole face through 0.125mm thick capton film[3]. There may be a proper and uniform thermal contact between the pole tip and the trim coils. Thermal contact between the iron core and the main coil or air is relatively small. With this structure, under small temperature variation, the thermal expansion of the magnetic gap is mainly determined by the temperature of the trim coils. The variation of the magnetic gap causes drift of the magnetic field. Field drift of -1.6×10^{-5} /day corresponds to temperature change of 0.5°/day. So it is possible to stabilize the magnetic field with controlling the temperature of the trim coils. The temperature change other than that of that of trim coils can be compensated by the temperature of the trim coils. By adjusting the temperature of the cooling water for the trim coils, the stability of the magnetic field better than 1×10^{-6}/week is achieved.

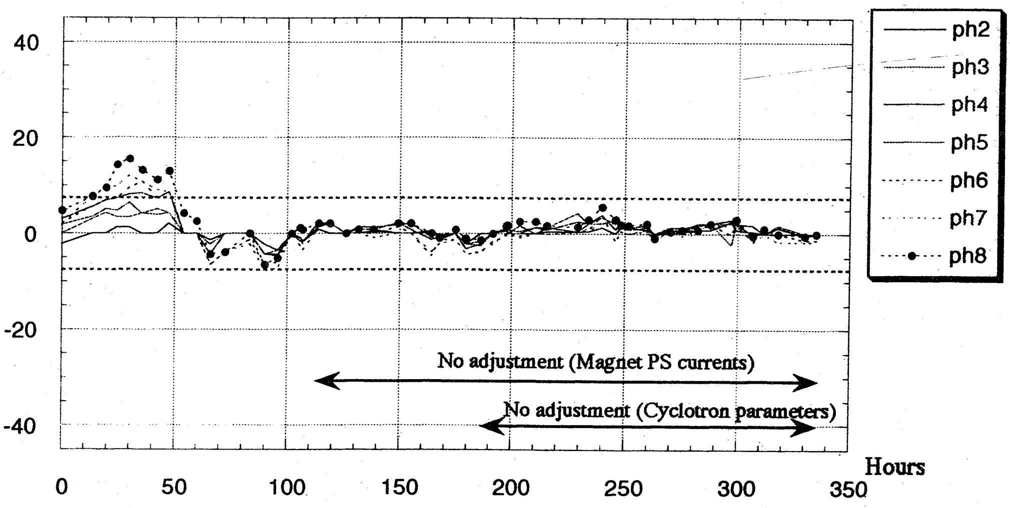

Fig. 5 Trend data of the Proton beam phase monitored for a period of 2weeks. Extracted energy is 300MeV.

Together with the highly stabilized RF system, high quality beams are accelerated stably for long times. The high beam quality is kept more than 150 hours without any readjustment of the parameter of the accelerator. Fig. 5 shows trend data of the accelerated beam phase. The beam phase is monitored by the eight non-intercepting electrodes. Each electrodes is placed radially at equal intervals. The figure shows the phase relative to the signal of the inner most phase monitor. The beam current was few-thenths of a nA to 1μA. The beam current was ajusted with a slit or the ion source which are eqipped on the injector system. Typical energy spread was ~300KeV independent of beam current.

References

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