4.2 RCNP TECHNIQUES FOR PRODUCING ULTRA-PRECISE BEAMS

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In the RCNP, high-quality beams in momentum spread have been strongly required. Recently, we have succeeded in producing ultra-precise beams. For example, the ratio of the energy spread to the beam energy (DE/E) is achieved in 2000 as » 1.5x10^{-4} both for 392 MeV and for 300 MeV protons.

A new beam line which accomplish both lateral and angular dispersion matching with the Grand Raiden spectrometer was designed and constructed in 2000[1]. In dispersive mode, the energy distribution of the beam itself can be principally cancelled out. In the commissioning experiments, energy resolutions of DE = 13.0 – 0.3 keV and DE = 16.7 – 0.3 keV in FWHM were achieved for 295 MeV and 392 MeV protons[2], respectively, i.e., DE/E » 4x10^{-5}. Even in dispersive mode, an energy resolution of the beam itself is much important practically. The lateral size of the beam on a target point is approximately proportioned to the momentum spread of the beam itself, which means that a high-quality beam is experimentally expected. Requirement for beam stability is also much harder than that for achromatic transport mode. An ultra-precise and stable beam, therefore, is also needed in dispersive mode.

It was already found that the magnetic field of a cyclotron is one of the most important experimental parameters for ultra-precise and stable beam [3]. At that time, Only the magnetic field of the Ring cyclotron was measured by an NMR probe. Recently, two NMR probes attaching small field correction coils had been installed in the AVF cyclotron and we have succeeded to measure continually the magnetic field of the AVF cyclotron with the resolution of 0.1 mT [4]. It was found that the magnetic field of the AVF cyclotron also strongly correlates with quality of beams. Figure 1 shows the magnetic field of the AVF cyclotron for 392 MeV proton as a function of a relative time t. Magnetic field increased with a rate of DB/B » 1.2x10^{-5} per day without any operation. The field of the Ring cyclotron was much stable at that time. The energy spread was intermittently measured by the users. When the energy resolution became significantly bad, the main coil current of the AVF cyclotron was adjusted. Energy resolutions before adjustment of the magnetic field and after adjustment are also shown in Fig. 1. For example, at t = 24, the energy resolution before and after adjustment are 180 keV and 83 keV, respectively. The energy resolution was roughly represented when the magnetic field was represented. For t > 50 hours, the suitable magnetic field strength decreased by about 5 mT, the reason of which may be that non-uniform deformation of the magnet pole and the return yoke happened. The frequency to change the coil current was only about 5 times per day. It should be noted that the resolution of the NMR probe in the AVF cyclotron is precise enough to operate the cyclotron and to obtain ultra-precise beams.

From fig. 1, it is found that the magnetic field of the AVF cyclotron needs to be controlled on the order of 10^{-6}. Using the main-coil power supply, we need to control the current by a few mA in comparison with the total main coil current, » 574 A, in this case. Therefore, in order to adjust the magnetic field in very detail, it is not so suitable to use the main coil current. In 2000, a one-turn coil called fine tuning coil (FT coil) was installed to the AVF cyclotron. Typical current is » 10 A. Current control of a few tens mA leads to control the magnetic field on the order of 10^{-7}.

As shown in Fig. 1, the energy spread of the beam strongly correlated with the magnetic field strength. For long-term stable operation of an ultra-precise beam, a drift of the magnetic field should be avoided. It should be pointed out that a feedback control by coils should be minimized for long-term operation of an ultra-precise beam, because non-uniform deformation of magnet pole and return yoke due to thermal effect should be avoided in keeping the isochronism at any radii. In 2000, a cooling system of the AVF cyclotron was improved. Main purposes are 1) to control the water temperature for the main coil independently and 2) to stabilize the water temperature both for the main coil and the trim coils by the order of 0.1 degree independently of outer circumstance. For the former, an additional water pump and heat exchanger was installed for the main coil. For the latter, a three-way valve was newly installed nearby the cooling tower in order to cancel out influence on outer disturbance. A new buffer tank for chilling water was also installed.

Stability of the magnetic field of the AVF cyclotron was measured by using the new cooling system. Temperature both of the pole and the yoke surface stayed within 0.1 degree over 80 hours. The magnetic field kept the level within – 2x10^{-6} during this period. Even the energy spread of the beam was not measured at that time, we are convinced that an ultra-precise beam should be obtained without any significant adjustments of the cyclotron parameters.

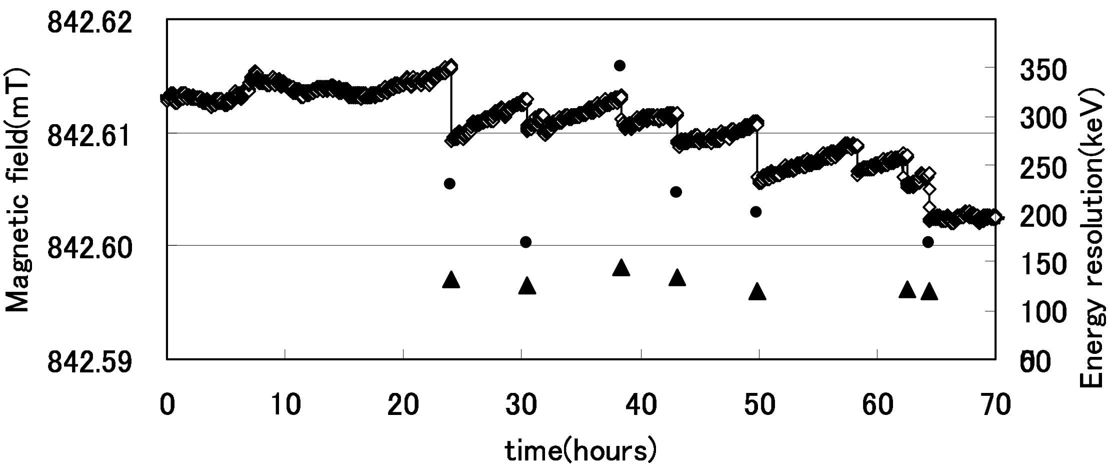

Figure 1: Magnetic field of the AVF cyclotron (open diamond). Energy resolution before adjustment (solid circle) and after adjustment (solid triangle) of the main coil are also shown.

References

[1] T. Wakasa et. al., RCNP Annual Report 1999 p.95.

[2] S. Ninomiya et. al., elsewhere in this report.

[3] T. Saito et. al., RCNP Annual Report 1997 p.286

[4] S. Ninomiya et. al., RCNP Annual Report 1999 p.110