Measurement of the beam characteristics in the AVF cyclotron

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High-quality beam in momentum spread have been strongly required and successfully produced in the RCNP cyclotron complex, which consists of the Ring cyclotron as a main accelerator and the AVF cyclotron as an injector. Thus, single component beam at a target point is required. Single-turn extraction from the AVF cyclotron was, however, not realized for a normal operation for several reasons[1] and extracted beam from the AVF cyclotron is cut by beam slits. Recently, quasi-single-turn extraction from the RCNP AVF cyclotron had been realized for helium-3 beams[1]. At that time, however, such extraction was not achievable for proton beam, which is the most required beam in the RCNP.

Fixed internal phase probes of the AVF cyclotron, which had been preliminary tested in 2002, were improved and newly installed in 2003. The radial positions of the probes are 270 mm, 370 mm, 470 mm, 570 mm, 670 mm, 770 mm, 870 mm, 933 mm and 998 mm, respectively. The widths of the inner seven probes are 50 mm and others are 38 mm. Isochronous field was experimentally ensured in this range. Using this phase probes, it was found that isochronous condition was not sufficiently realized for some beam including proton beam and trim coil current was changed.

The Rf voltages of the AVF cyclotron were also increased in order to widen turn separations. A position of the phase defining slit in the central region was also moved to outer side.

Figure 1 shows 65 MeV proton beam currents measured by a differential probe and an integral probe in the RCNP AVF cyclotron. Quasi-single turn extraction has been realized. In more inner region, not well-separated but distinguishable turn structure were observed. In 2003, Quasi-single-turn extraction has been realized for almost all particles.

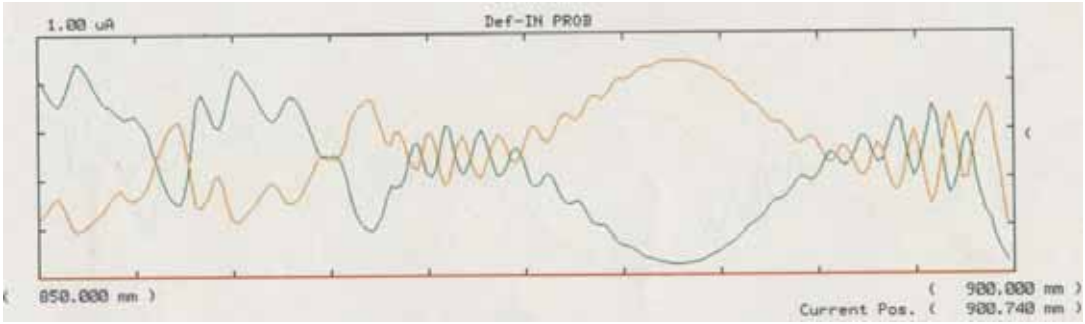

Figure 1 65MeV Proton beam currents as a function of a position of the beam probes

Turn separations for 65 MeV proton beam are obtained as a function of a radius, R, of the AVF cyclotron which is shown in fig. 2. Very small separations were not distinguished. Observed turn separations have periodical structure.

When we have no harmonic magnetic fields, turn separation, $\Delta r(R)$, consists of two components, i.e.,

$$\Delta r(R) = \Delta r_{rf}(R) + \Delta r_{oc}(R) \qquad (1),$$

where $\Delta r_{rf}(R)$ is turn separation by beam acceleration due to Rf electric field and $\Delta r_{oc}(R)$ is that by rotation of a orbit center of beam, respectively. Therefore, a Dee voltage, V_{dee}, is estimated from averaged turn separation. The obtained Dee voltage from fig. 2 was 57.1 kV which is consistent well with that obtained by direct electric-field pick-up measurement, 57.9 kV. This agreement also represents that the beam was accelerated at the top of the Rf voltage.

The turn separation by a rotation of a orbit center,, $\Delta r_{oc}(R)$, is represented as follows,

$$\Delta r_{oc}(R) = 2\pi(\nu_r(R)-1)x_0 \cos\left\{2\pi\sum(\nu_r(i)-1)+\theta_0\right\} \qquad (2),$$

where $\nu_r(R)$ is radial focusing frequency, x_0 is difference between orbit center and machine center and θ_0 is a constant, respectively.

In an AVF cyclotron, a negative magnetic field gradient is introduced at small radii in order to obtain strong axial focusing at central region. In the RCNP AVF cyclotron, isochronous magnetic fields were designed to start at about R = 200 mm for 67 MeV proton[2]. We have five sets of valley coils but used only two sets, i.e., innermost one and outermost one. Therefore, the condition of eqs (1) and (2) were satisfied in the range of R=350 – 750 mm.

Assuming perfect isochronous magnetic field, four independent parameters are included in eqs (1) and (2), i.e., V_{dee}, $\nu_r(R)$, x_0 and θ_0. The value of V_{dee} was set to 57.1 kV. Designed radial focusing frequencies, which have already reported[2], were used as the values of $\nu_r(R)$. The values of x_0 and θ_0 were searched by eye fitting and the values of x_0 is set to 3.4 mm. Calculated turn separations are also shown in fig. 2. Measured turn separations agreed quite well with calculations from 400 mm to 700 mm. Slight difference at R < 400 mm might be caused by introduced harmonic field by the valley coil #1.

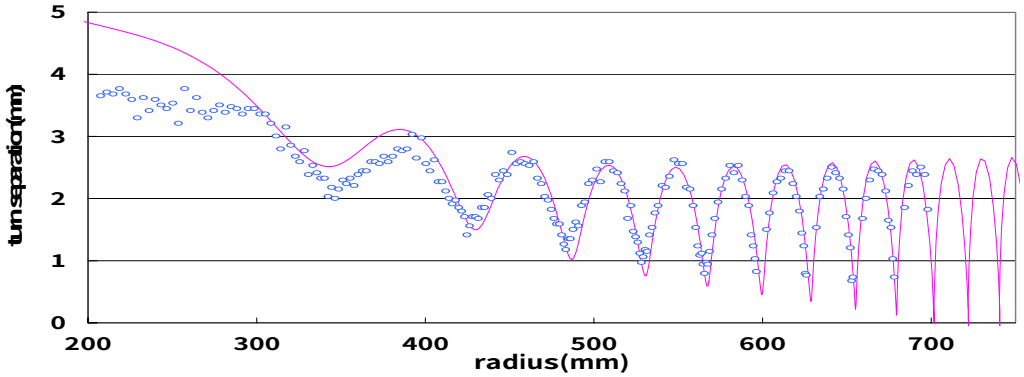

Figure 2:Observed (circle) and calculated (line) turn separations as a function of a radius.

References

[1] S. Ninomiya *et. al.*, RCNP Annual Report 2002 p.152.

[2] T. Yamazaki *et. al.*, RCNP Annual Report 1976 p.52.