VIII. 1 Acceleration Tests

Several acceleration tests have been performed after the acceptance test of the cyclotron.

A) Determination of the optimum acceleration parameters

In the case of our cyclotron about 40 parameters are needed in order to accelerate a given particle (at a given energy). Concerning the various coils of the cyclotron we use the theoretical values calculated from the results of the field mapping except for the current of the last trim coil (No. 8), and we determined the remaining parameters for an energy step of $AE = 1$ or $2$ MeV for all the particles ($^4$He, $^3$He, d and p) in actual operations of the cyclotron. The purpose of this parameter search is to obtain the maximum extraction efficiency, maintaining as far as it is practical the condition of constant-orbit acceleration; the positions of the ion source, the puller (this is not movable) and the deflector are fixed except for the fine tunings. The dee voltages, the deflector voltage, the current of the last trim coils (No. 8) and the phase difference between the two dees were determined semi-empirically in actual operations.

Fig. 1 shows the extraction efficiencies obtained for the various particles and energies. In most of the cases, the extraction efficiency is higher than about 65 %. The relation of dee voltages vs. energy is shown in fig. 2. The dee voltage roughly follows the scaling law$^1$ (the dee voltage be proportional to particle energy/charge) except at low and high energies. At low energies, empirical dee voltage is higher than that of the scaling law because of the necessity of avoiding the multipactoring, and at high energies it is maintained to be relatively low in order to avoid RF discharge. Fig. 2 indicates that the dee voltage No. 2 is always higher than the dee voltage No. 1, this fact may be related with the probrem of the beam centering. The discontinuity in the neighborhood of $E_p = 15$ MeV is due to the different harmonics of acceleration; \( H = 4 \) for $E_p < 15$ MeV and $H = 2$ for $E_p > 15$ MeV.

Fig. 3 shows the deflector voltage vs. energy. The deflector movement has five degrees of freedom; the input and the output positions, the input and the output gaps and the septum curvature. In most cases, however, a fine tuning of only septum curvature was necessary. The relation of deflector voltage vs. energy follows rather well the scaling law mentioned above.

B) Measurement of the differential beam profile

The radial differential probe ($\Delta R$ probe) was used to see the radial beam quality. The radial resolution of the probe is about 0.5 mm. A typical beam profile is shown in fig. 4. We note that the turns are clearly separated over the whole range from the central region to the extraction region and that the beam is well centered. The turn separation was 9.5 mm at $r = 100$ mm and 2.5 mm
at \( r = 650 \text{ mm} \), and the total number of turns could be counted to be 202. Also, fig. 4 shows that the well centered beams and the consistency with the results of the phase-history experiment.\(^2\)

C) Measurement of the time distribution of the extracted beam

Knowledge of the time distribution of the extracted beam is useful for timing experiments. Since the frequency of the RF system of our cyclotron is rather high (20-40 MHz), the correspondingly narrow pulse width of the beam can be expected. The pulse width of the beam was measured by taking a coincidence between the RF signals and gamma-rays produced at the beam stopper in the external beam line. The block diagram of the measurement is shown in fig. 5. Fig. 6-a) and 6-b) show the timing distribution of the beam on the dee voltage No. 2 to which the puller is attached and on the current in the last trim coils (No. 8). In fig. 6-a), the \( V_{D1} = 34.4 \text{ kV} \) gives the maximum extraction efficiency, whereas \( V_{D2} = 35.0 \text{ kV} \) gives the minimum pulse width. This indicates that the pulse width of the beam is quite sensitive to the dee voltage and that the dee voltage giving the maximum extraction efficiency is somewhat different from that giving the minimum pulse width. Fig. 6-b) shows that the pulse width depends also on the current of the trim coils (No. 8), but the dependency is rather weak. Fig. 7 shows the time distribution for 10 MeV at protons where the parameters of cyclotron were adjusted in order to obtain the minimum of the pulse width neglecting the extrationon efficiency. Although the extraction efficiency was as well as 20 %, the pulse width was obtained 360 psec. This narrow pulse width is one of the merits of the high frequency of the RF system of the Tohoku cyclotron.

References
2) Sera K., et al., in this issue.

Fig. 1 Measured extraction efficiencies over a wide range energy for proton and \(^{4}\text{He}\). The extraction efficiency is defined by the ratio of the beam current of the external beam stopper to that of the main probe at 650 mm (Extraction radius is 680 mm).
Fig. 2  Dee voltages adjusted to obtain the maximum extraction efficiency. Channel 2 indicates the dee electrode to which the puller is attached.

Fig. 3  Deflector voltages adjusted to obtain the maximum extraction efficiency. H2, H3 and H4 indicate the harmonic modes of acceleration. The radio-frequency system operates at a frequency which is multiple H, the harmonic, times the particle frequency: $f_{rf} = H f_p$. 
Fig. 4  The differential beam profile for $^{3}\text{He}$ at 50 MeV.

Fig. 5  Experimental set-up for measuring the time distribution of the beam.
Fig. 6 The dependence of time distributions of the beam on the acceleration condition for 20 MeV deuteron
(a) dependence on the dee voltage
(b) dependence on the current of the last trim coils (No. 8)
(Each peak corresponding to trim coil current was sequentially measured by shifting the horizontal axis.)
Fig. 7  The maximum width of the beam pulse obtained at the Tohoku cyclotron for 10 MeV protons. Small peaks correspond to gamma rays coming from the slits in front of the beam stopper.