STATUS REPORT OF THE TOHOKU AVF CYCLOTRON

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Abstract.- The Tohoku multi-purpose AVF cyclotron (CGR-MeV Model 680) has an extraction radius of R = 680 mm and a K-number of 50 MeV. The first beam was extracted in December 1977, and its beam has regularly been used for many experiments by the users of this university from July 1979. Outline of this cyclotron, beam transport system, some results of measured beam-characteristics and developed instruments are briefly described.

1. Introduction.- The AVF cyclotron and its related facilities at Cyclotron and Radioisotope Center (CYRIC) were funded by the Ministry of Education for the fiscal years of 1974-1977 and have been intended for wide applications in various research fields. The fundamental design of this cyclotron was undertaken by CGR-MeV, France, and the machine was constructed by Sumitomo Heavy Industries, Japan. The construction of the cyclotron started in July 1974, and the cyclotron gave the first extracted beam in December 1977.[1] After the performance tests of the cyclotron including beam transporting, together with the tests of research instruments associated with the cyclotron, preliminary experiments began in February 1979. Finally, the machine and related facilities have been opened to the users of this university from July 1979.

The CYRIC cyclotron (Model 680) is one of four-sectored variable-energy AVF cyclotrons; it accelerates protons up to 40 MeV, deuterons to 25 MeV, ^{4}He to 50 MeV and ^{3}He to 65 MeV. The average induction at R_{ext} = 680 mm is 15 kG in maximum, and the induction over hills is 18 kG in maximum. The radio-frequency system consists of two 60° dees (one has a fixed puller) connected to resonant cavities which are excited by two RF amplifier chains (MOPA) and tuned automatically by rotary pedals. By selecting the relative phase (ϕ_{rela}) between two RF signals on the two cavities, three modes of harmonic acceleration, namely H = 2, 3 and 4, are realized. Such a harmonic acceleration with the fixed puller configuration shows a unique characteristic of this cyclotron; two dee voltages and ϕ_{rela} can be independently adjusted.

The beam-transport system for the CYRIC cyclotron has seven beam lines for different purposes. A layout is shown in fig. 1. Beam lines [1] and [2] are for radioisotope production with solid, liquid and gas target systems, [31] for on-line isotope separation and material irradiation, [33] for atomic physics and particle-induced X-ray analysis, [34] for in-beam β and γ-ray spectroscopy. Beam line [41] has a pair of dipole magnets for beam analysis and gives a high resolution beam, [51] is for fast neutron time-of-flight measurements and has a beam swinger consisting of two dipole magnets.

Horizontal and vertical slits are placed at a location 4.4 m downstream from the exit port of the cyclotron, and a stigmatic image is formed at the slits by adjusting acceleration and extraction parameters together with a Q-triplet. Futhermore, a high-speed beam emittance analyser[2], installed at the exit port of the cyclotron, makes an efficient beam transport possible.

2. Operation, Maintenance and Developments[3].- Cyclotron beam time is scheduled every 3 months, during which 8 weeks are acceleration periods and are opened to the users. The daytime of every Monday and Tuesday is assigned to regular maintenance, acceleration tests and developments. The beam time for users is 87 hours/week from Tuesday evening to Saturday morning. The scheduled beam time distribution covers many fields of research; i.e., nuclear physics, atomic and solid state physics, nuclear medicine, nuclear chemistry, biology, element analysis, R.I. production, material irradiation and other applications. The partition of beam time in 1980 is listed in table 1.

a) Operation

Several acceleration tests have been performed to determine the optimum acceleration parameters and to

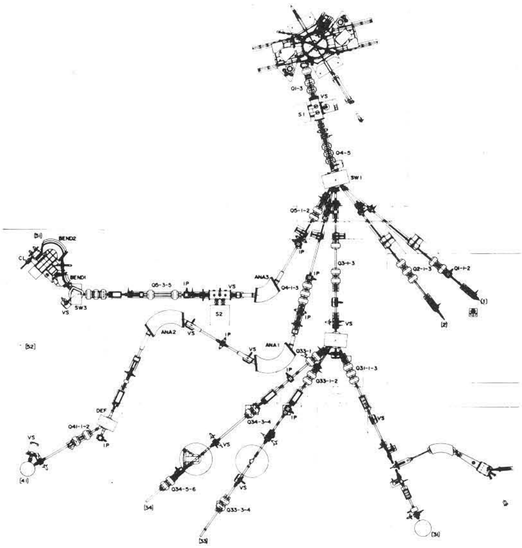

Fig. 1 : General lay-out of the beam transport system.

examine the internal beam properties.

The acceleration parameters are roughly in accordance with the principle of "the constant orbit acceleration", and the positions of the ion source, the puller and the deflector are fixed (except for fine tuning); the dee voltages are adjusted following the scaling law$^{4)}$ except for operation at lower and higher energies. At lower energies, practical dee voltage is higher than the expected value from the scaling law so as to avoid the multi-pactoring, and at higher energies the dee voltage is relatively lower to avoid RF discharge. In most cases, the extraction efficiency is estimated to be higher than 65 %.

The radial differential probe with 0.5 mm resolution was employed (ΔR probe) to find the radial beam quality. Fig. 2 shows a typical beam profile for 50 MeV-^{3}He. The turn separation was 9.5 mm at a radius of 100 mm and 2.5 mm at R = 650 mm.

The RF system with a high frequency range of 20~40 MHz is expected to yield narrow beam pulses, which is suitable for fast-timing experiments. The pulse width of the beam was obtained by measuring the time interval between the RF signals and gamma-rays produced at the beam stopper installed in the external beam line. The pulse width was rather sensitive to dee voltages. The obtained minimum value was 360 psec. This narrow pulse width is one of the merit of the high frequency RF system.

Phase history of the internal beam was measured by; (1) the γ-ray timing method and (2) a $\Delta\omega$ method for the same acceleration condition. Method (1) easily gives the relative phase between the timing signals from the γ-rays produced by particles impinging on the internal probe and the RF timing signal, and method (2) gives absolute phase value from the beam intensity distribution versus R for various $\Delta\omega \lesssim 0$. The primary $\Delta\omega$ method, which was proposed by Garren et al.$^{5)}$, is applicable only to a single 180° dee. Hence, we use the modified equation which is applicable to a double dee system with an arbitrary dee angle.$^{3)}$ Fig. 3 compares the measured phase histories of the same particle and energy obtained for different harmonics of acceleration. As seen in these figures, the higher the harmonic number is, the worse the isochronous condition is realized.

Table 1. Partition of beam time and accelerated particles from January 1980 to December 1980

1) Nuclear physics	1220	hr
2) Atomic and solid state physics	316	
3) Material Irradiations	196	
4) R.I. Productions*	216	
5) Life science (Nuclear medicene, Biology, etc.)	178	
6) Element analysis and other applicaitons	222	
7) Maintenance and developments	227	
	2575	
p (3 40 MeV)	1230	hr
d (5 25 MeV)	29	
^{4}He (10 50 MeV)	949	
^{3}He (7 65 MeV)	367	
	2575	

*; These are mainly for chemistry, physics and technology. Short-lived R.I. productions for nuclear medicine are included at 5).

b) Maintenance

The frequency of troubles of the cyclotron has been relatively small and is decreasing. Some of these were the leakage of water from the cone of the ion source, the cracks on the flexible plate joining the rotary pedal with the cavity wall, the break down of sliding contact inside the cavity, the damage of stainless-steel framework in the dee and of electronic parts of such as diodes used in various power supplies. The pre-septum of the deflector was replaced four times. These troubles were repaired quickly with no serious damage to the scheduled beam time.$^{6)}$

c) Developments

In order to find the beam quality and to obtain easily the best beam transportation, the emittance measurement system was developed and installed as mentioned above. This system works on the principle of one-slit multidetectors method and is controlled by a micro-computer. It takes only one minute to obtain the phase-space contours and the current-density distributions in a phase space. Fig. 4 shows the principle of the one-slit multidetectors method for the emittance measurement. Fig. 5 shows the current-density distribution in the phase space (a), and the phase-space contour (b). For matching of the cyclotron beam to the

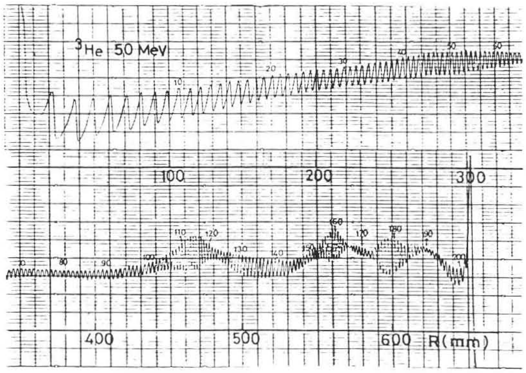

Fig. 2 : A differential beam profile for ^{3}He at 50 MeV.

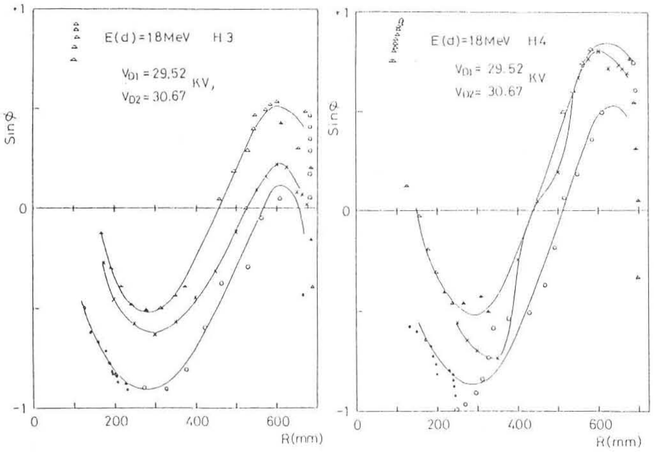

Fig. 3 : Phase history of 18 MeV deuterons accelerated in the third (H3) and fourth (H4) harmonics. Circles and triangles indicate the lower and the upper phase boundaried, respectively, and cross-mark points indicate the central phase from the timing measurements.

beam transport line, this emittance system has been found to be quite useful and effective.

The feasibility of heavy-ion acceleration in CYRIC cyclotron has been tested by using the ordinary ion source (hot-cathode type PIG) for light ions. Since this ion source was designed mainly for obtaining a high current ^{4}He beam, and has large cross sections in the chimney and filament, it is expected that accelerations of heavy ions such as $^{14}N^{3+}$, $^{14}N^{4+}$, $^{12}C^{3+}$ and $^{12}C^{4}$ are possible. In the acceleration of the $^{12}C^{3+}$ beam, a beam current of 100 nA was obtained at the external beam stopper. Furthermore, we developed a cold-cathode PIG heavy-ion source to accelerate more intense and higher charge-state heavy ions. This result is also reported elsewhere in these proceedings.

A new phase slit with a variable gap width has been installed to improve the beam quality. This slit is a powerful tool to eliminate unwanted beams at the central region.

3. References

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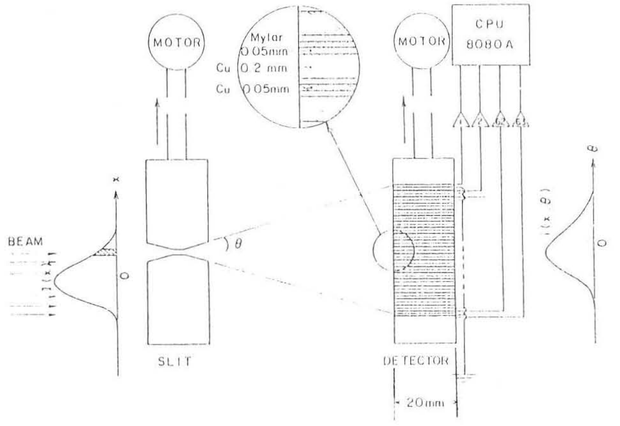

Fig. 4 : Principle of the one-slit multidetectors method for emittance measurement. The notation I(x) is the current-density distribution in the space and i(x,θ) is that in the phase space.

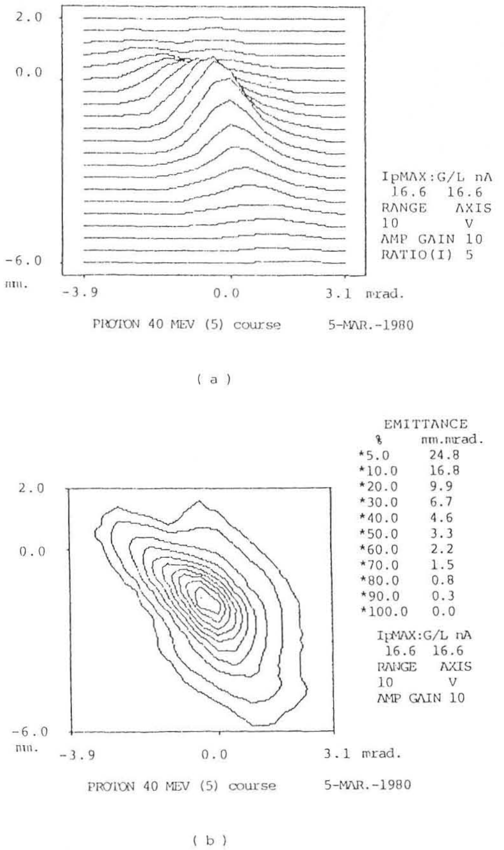

Fig. 5 : Display of the emittance of 40-MeV proton beam.
(a) current-density distribution in the phase space.
(b) phase-space contours: the horizontal axis is in unit in mrad and the vertical axis is in mm.