THE TOHOKU UNIVERSITY 680 MODEL CYCLOTRON AND FACILITY

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Abstract

The acceptance test of the 680 model cyclotron at the Cyclotron Radioisotope Center of Tohoku University was completed in December, 1977. The fundamental design is that of CGR-MeV, France, and the machine was constructed by Sumitomo Heavy Industries. Based upon the experience of the first machine of this model built at CNRS (Orleans, France), some modifications to boost proton energy from 38 MeV to 40 MeV were carried out.

During the acceptance test, an emittance measurement at 40 MeV proton energy with 40 μA extracted current was conducted in order to have accurate information for delivery of beam through the beam transport. The emittance was 22 and 31 mm mrad at the X and Y axes, respectively. A simple beam energy resolution experiment also was carried out, namely the measurement of elastic scattered particles from a thin foil of iron, using an SSD.

1. Introduction

This cyclotron and its related facilities were funded by the Ministry of Education in 1974 and intended for wide application in various fields. One of the major features of the beam transport is a TOF system for accurate measurement of neutron spectra with energy resolution better than 0.2%. To achieve this accuracy, a 40 m drift duct has been installed and beam chopping of $^1/_{25}$ of the cyclotron beam is obtained by two successively arranged beam choppers. An isocentric beam transport was also furnished to change the beam's angle of incidence against a target.

Another feature is an analysing system, consisting of a pair of 105° and 95° magnets with homogeneous field and edge focusing. The energy resolution is designed to be better than $^1/_{3000}$. Two target stations are provided for RI production, and irradiated samples are transferred to a hot laboratory by a rabbit transfer system.

In August of this year a 10 MeV α beam reached the target station, and in September the beam distribution test for all beam lines will start. Fig. 1 shows a general layout of the cyclotron facility.

2. Outline of cyclotron

The model 680 cyclotron, K=50, was designed to be a versatile, variable energy cyclotron having two 60° angle dees with 4 sectors: it falls between the CGR-MeV high energy 930 model and the compact 520 model (Fig. 2). The choice of 60° angle dees gives a small dee capacitance and enables the use of high radio-frequencies from 20 to 40 MHz. Acceleration can be achieved in the 2nd, 3rd, and 4th harmonic modes.[1]

Careful investigation of the central region suggested the use of a single fixed puller with a roughly fixed orbit for all energy and particles.[2] This new design proved successful during the beam test, when very narrow position adjustments of the ion source were enough to produce all ranges of energy and particles.

As shown in Fig. 3, a MOPA system was employed. The three kinds of regulation loops give stability of dee voltage within 0.1% and phase angle of two dees within 1°. The cavities are of a moving panel type, allowing frequency variation without any sliding contacts by movement of a rotary panel along a curved wall.

Automatic tuning of cavities also is achieved by moving the rotary panels, while keeping the phase angle between the control grid and the plate of power tubes at 180° with a feed-back loop which consists of a phase discriminator and a motor driving device. A coupling loop feeds power into the cavity. This coupling is adjusted by turning the angle of the loop relative to the cavity: several trials were made during the test. The power tube supply is equipped with a crow-bar circuit, and the voltage can be altered by changing the taps of the transformers.

Cooling of the cyclotron is achieved through circulation of deionized water at 30 ± 1° C. The temperature regulation is adopted to ensure the stability of the power supplies and the radio-frequency system.

Two kinds of ion source of vertical installation are provided in this cyclotron. One of them is a hot cathode type of Livingstone-Jones for production of p, d, ^3He, and α ions. The other is a cold cathode type of PIG for acceleration of such heavy ions as $^{14}N^{4+}$, $^{14}N^{5+}$, and $^{12}C^{3+}$, and specially designed to be exchangeable with the hot cathode type, having the same central plug and driving unit.

Main characteristics are summarized in Table 1.

Table 1

Main characteristics of the 680 cyclotron

Magnet	
Weight (metric tons)	110
H x W x L (m)	2.3 x 1.7 x 3.72
Pole diameter (mm)	1600
Number of sectors	4
Number of circular coils (pairs)	8

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Number of harmonic coils (pairs)	4
Maximum average field at extraction radius (kG)	15
Radiofrequency	
Number of dees	2
Number of cavities	2
Dee angle (°)	60
Maximum dee voltage (kV)	50
RF available power (kW)	2 x 55
Extraction	
Electrostatic deflector	1 set
:Maximum field (kV/cm)	130
:Angular span angle (°)	55
Magnetic channel	passive

3. Beam Test

The results of the beam test are summarized in Table 2. The beam test points were selected to cover the maximum and minimum energy of the guaranteed energy region.

Table 2

Results of beam test

PARTICLE & ENERGY	guaranteed CURRENT	measured CURRENT	measured EFFICIENCY
proton MeV	μA	μA	%
3	15	15 (1)	43.5
15	30	100	65
25	50	50	63
39.5	40	50 (2)	71.5
deuteron			
5	15	15	47
10	35	60	69
25	50	52	66
helium 3			
7	10	11.5 (3)	30
20	30	38	50
50	40	40	66.5
65	30	40	60
helium 4			
10	10	32	54
20	20	50	67
50	30	30	64

measured ENERGY (1) H_2^+ 5 MeV
(2) 40 MeV
(3) 7.2 MeV

Prior to the beam test, it was found that the strength of the central magnetic field bump was insufficient for the focalization of beam. After trying computation with the aid of a two-dimensional magnetic map program, we selected two sets of central plugs that were made from soft iron and Fe-Co alloy, and conducted magnetic measurements again in the vicinity of the central region. For this procedure a magnetic measurement wheel was devised in order to make the measurement without disassembly of the vacuum chamber. Finally, a set of Fe-Co alloy plugs was chosen. A sample profile of the magnetic field, fitted to an isochronous field of α 50 MeV, is shown in Fig. 4. In actual tests it has been proven that our computed setting parameters for the circular coils were quite correct: no fine tuning was needed. The actual beam profile for a 50 MeV α beam is shown in Fig. 5. Only a comparatively small amount of beam loss appears in the central region.

4. Emittance measurement

The emittance was measured by using two sets of motor-driven slits for the horizontal (X) and vertical (Y) directions with 40 MeV proton beams of 20 and 40 μA current. The slits were installed at a position just after the first set of triplet Q magnets.[3] The distance between the slits was 1 m and the gaps of the slits were set at 0.5 mm. An example of the results on a recorder is shown in Fig. 6a, and the emittance profile of 85% beam current contour is shown in Fig. 6b.

The results of the measurements are summarized in Table 3.

Table 3

Emittance at 85% beam current (unit: mm-mrad)

Current	20 μA	40 μA
X axis	20.4	20.9
Y axis	21.7	27.1

Beam trajectories upon exit from the cyclotron can be estimated by tracing the beams back to the inside of the cyclotron, as shown in Fig. 7. The object points for the X and Y axes were obtained at distances of 1.7 m and 0.5 m, respectively, from the beam exit flange towards the inside of the cyclotron.

5. Energy resolution

The outline of the measurement method is shown in Fig. 8. A thin foil of 375 μg/cm^2 natural abundance of iron was placed at an angle of 45° against an incident α beam of 35 MeV. The particles scattered from the iron target were detected by a surface barrier type SSD. A couple of 2 mm diameter collimeters were placed in front of the SSD. The resolution of the SSD was estimated at 0.30% by observation of α particles emitted from ^{241}Am. The incident beam was kept as low as 3.5 μA to avoid pile-up effects. The energy spectrum is shown in Fig. 9.

Thus, the half width of the elastic scattering spectrum (0^+) can be estimated at 190 keV (0.63%).

After the subtraction of a kinematic effect (0.47%) arising from the beam spread in front of the SSD and the effect of the resolution of the SSD, the energy resolution of the beam can be estimated at about 0.3%.

6. Acknowledgements

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References

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2) A. Dupuis, J. Kervizic, B. Laune, G. Mayrand, D. T. Tran, and D. Tronc, ibid, 275.

3) W. Kuhlman, J. Bojowald, C. Mayyer-Boricke, and J. Reich, Proc. 5th Int. Cyc. Conf. (Butterworths, 1969), 348.

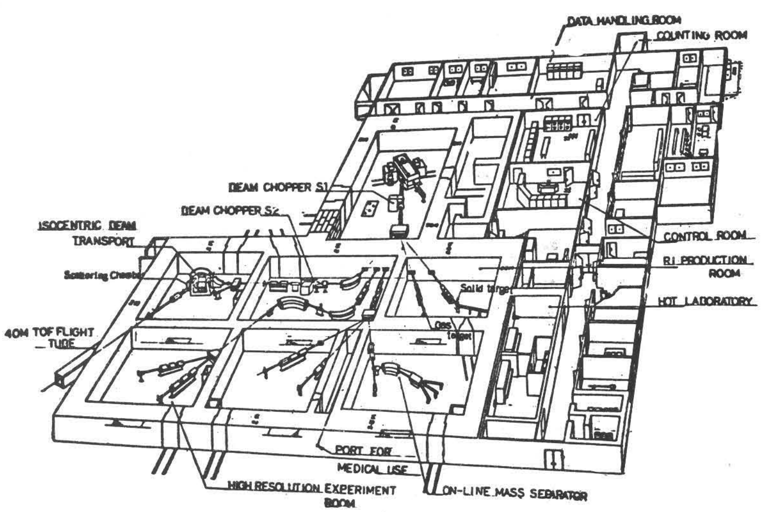


Fig. 1. Plan view of the cyclotron facility.

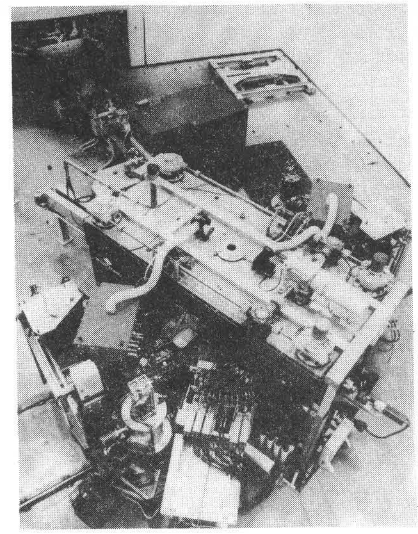


Fig. 2. Model 680 cyclotron and the external beam course.

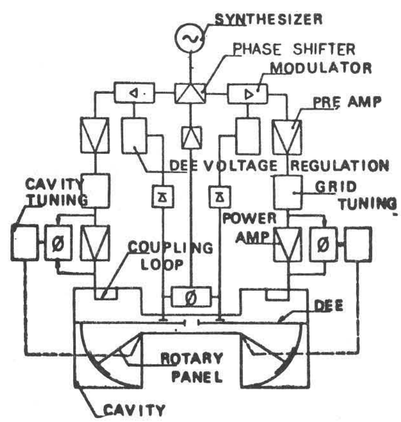


Fig. 3. Radio-frequency circuit diagram.

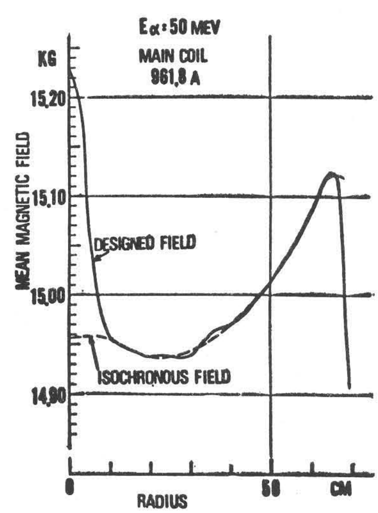


Fig. 4. Magnetic profile of radial direction.

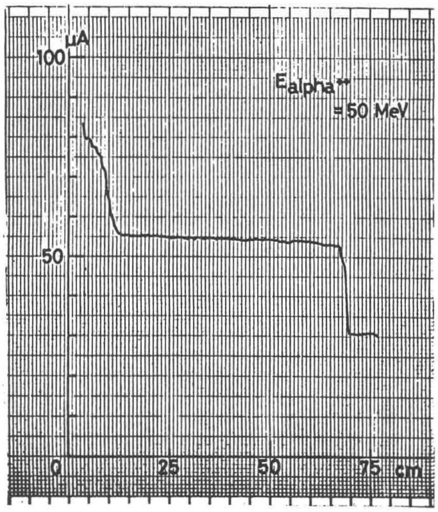
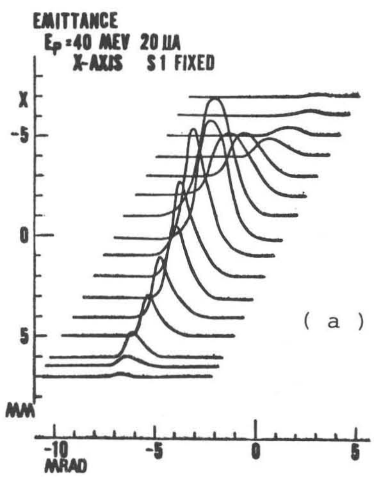
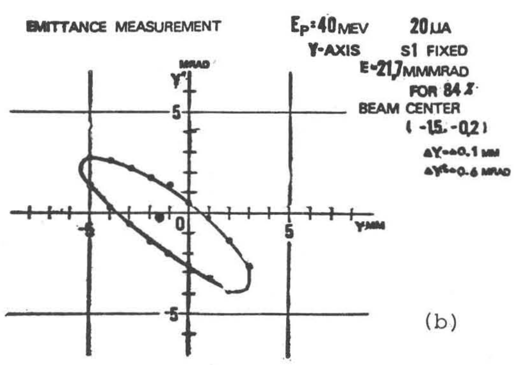


Fig. 5. Radial beam profile of the cyclotron.





Figs. 6a, & 6b. Vertical emittance of protons at 20 μA, 40 MeV.

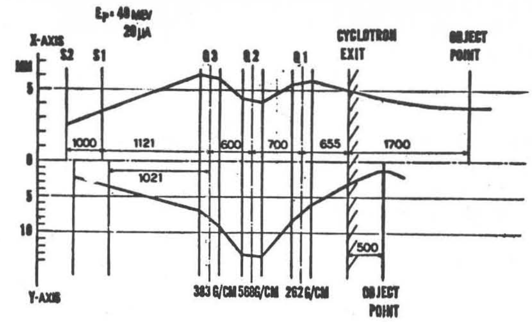


Fig. 7. Beam profile in the transport system.

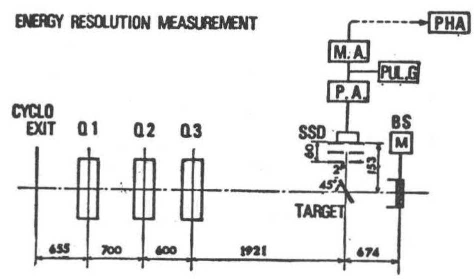


Fig. 8. Method of measuring energy resolution.

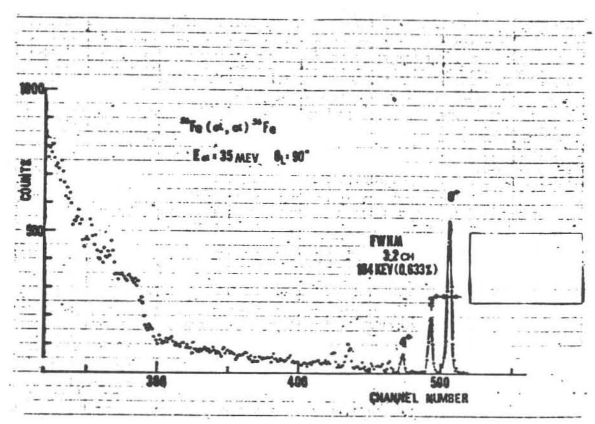


Fig. 9. Energy spectrum of α particles scattered by ^{56}Fe.