STATUS REPORT ON THE INS SF CYCLOTRON

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Abstract

The INS 176 cm Sector Focusing Cyclotron is a type of the variable energy and multi-particle acceleration. The first extracted beam was obtained in April, 1974. Eight target stations are now available for experiments.

This paper describes the status, operation experiences, performances and improvements.

1. Introduction

The INS SF cyclotron has three spiral sectors and a self-oscillator RF system. The beam transport system consists of low, medium and high resolution courses. Figs.1 and 2 show a plan view of the cyclotron and the layout of the beam transport system, respectively. Design study, mechanical structure and measurement of the magnetic field have been reported in the previous papers 1,2).

After the initial construction of the cyclotron was completed, various kinds of ions have been accelerated to various energies. In these operations, we had some troubles and we noticed that improvements on each element were required for obtaining a more stable operation and a better beam quality. Considerable efforts were devoted to improve the various parts of the cyclotron and develope new beams.

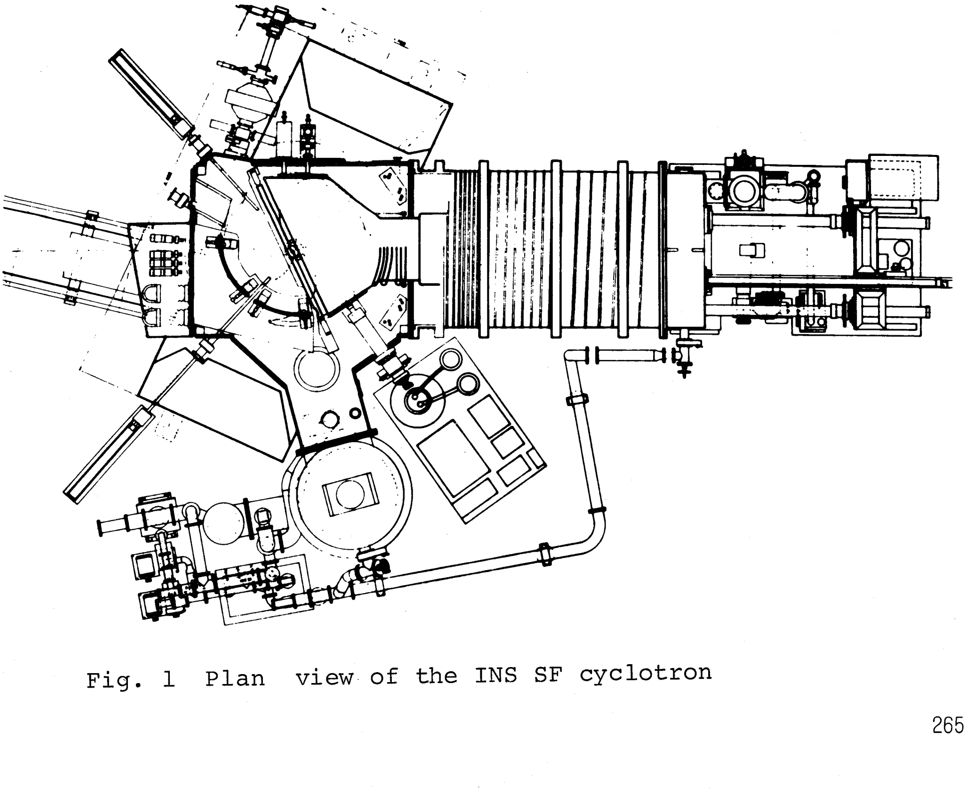

Fig. 1 Plan view of the INS SF cyclotron

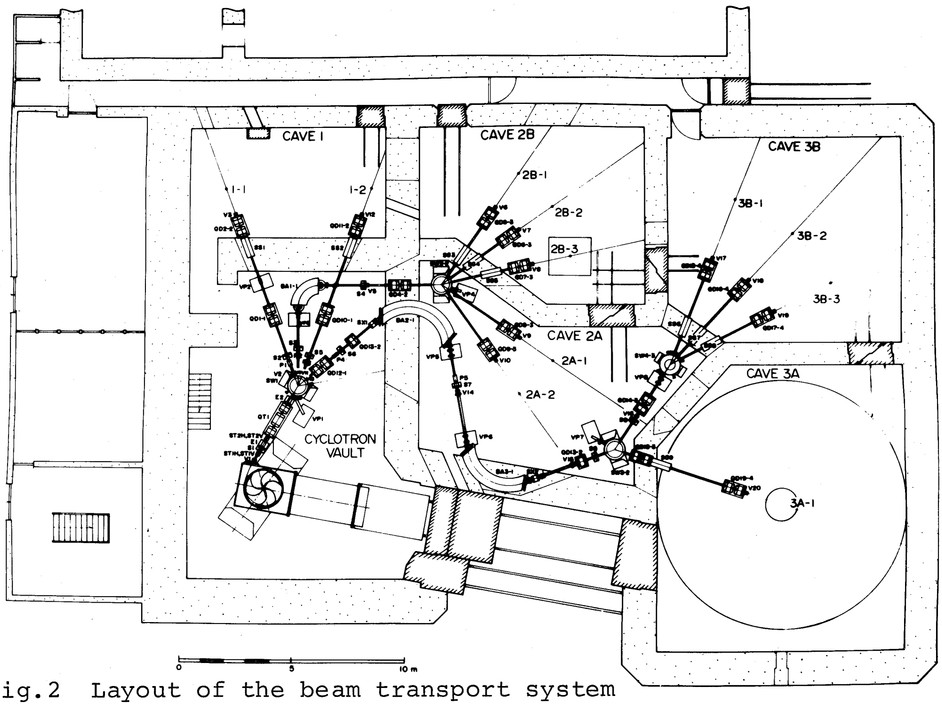

Fig.2 Layout of the beam transport system
Abbreviations are; V1=vacuum valve #1;ST1H=steerer #1, horizontal;S=slit and stopper box;E=emittance measurement device;QT=quadrupole triplet;VP=vacuum pump;SW=switching magnet;P=profile monitor;QD1-1=quadrupole doublet #1 operating on the power supply #1;SS=shield shutter;BA= beam analyzer;SX=sextupole magnet;2B-1=beam course #1 in the cave 2B.

2. Status and Goal of Performance

2.1. Variable energy and multi-particle acceleration

Table 1 shows the design values of the maximum energy and the achieved values of the energy and intensity for various kinds of ions.

A goal of the maximum proton energy is 48 MeV, while the achieved maximum energy is 35 MeV, which is restricted mainly by the limited frequency range of the self-oscillator RF system (see section 3.2.).

2.2 Beam transport system

The high resolution courses can be operated either in a dispersive or in a non-dispersive mode. Typical performances in the both modes to the 3B-1 course are as follows; about 2% of the extracted beam from the cyclotron is transmitted to the target in the dispersive mode with a beam spot size of 1.5 mm(W)x 2.5 mm(H), and about 25% in the non-dispersive mode with a beam spot size of 2.6 mm(W)x 5.2 mm(H).

The energy resolution was measured in the dispersive mode. The narrow resonance at 14.233 MeV in the excitation function of $^{12}C(p,p)^{12}C$ was observed. Horizontal widths of the object and image slits(S6 and S8 in Fig.2) were set to be 1 mm. The measured ΔE of about 2 keV was somewhat larger than the calculated resolution of 11500, which is corrected up to the second order aberration by using two sextupole magnets(SX1 and SX2 in Fig.2).

Table 1 Goal and status of the beam performance

Ion	Goal	Status(March, 1978)	
	Designed Energy (MeV)	Energy (MeV)	External Beam Currents
p	7 - 48	35	8 μA
p(pol.)	7 - 48	30	15 nA
d	13 - 34	34	8 μA
$^{3}\mathrm{He}^{++}$	19 - 90	90	8 μA
$^{4}\mathrm{He}^{++}$	25 - 68	68	8 μA
$^{12}\mathrm{C}^{4+}$	- 88	88	3.5 μA
$^{14}\mathrm{N}^{4+}$	- 76	40*	5.0 μA
$^{14}\mathrm{N}^{5+}$	- 118	115	4.3 μA
$^{16}\mathrm{O}^{5+}$	- 103	104	4.5 μA
$^{16}\mathrm{O}^{6+}$	- 153	129	0.23 μA
$^{20}\mathrm{Ne}^{5+}$	- 83	60*	0.1 μA
$^{20}\mathrm{Ne}^{6+}$	- 119	115	1.5 μA
$^{20}\mathrm{Ne}^{7+}$	- 162	150	0.02 μA

* 3rd harmonic acceleration

3. Cyclotron

3.1. Electromagnet

The cyclotron has 11 pairs of circular trim coils, of which 8 pairs are usually used, since we have only 8 power supplies. More power supplies are necessary for proton beam of a higher energy than the achieved.

3.2. RF system

The resonator is a coaxial type of a 1/4 λ mode with a movable short. The resonant frequency of the resonator ranges from 7.5 MHz to 22.5 MHz. The RF system consists of a booster, a self-oscillator, a dee voltage stabilizer and a frequency stabilizer. The power is supplied to the resonator through an RF coupler, which is a movable capacitor on the top of a coaxial feeder. The RF system is described in refs. 1 and 3.

In December of 1976, a serious damage to the coaxial feeder happened. The inner conductor was isolated with alumina insulators at the both ends of the feeder. In the first design, the space between the inner and outer conductors was in the vacuum. A high dee voltage operation of about 90 kV caused a discharge inside the feeder. After this damage, such a discharge took place even in a lower dee voltage. An alumina insulator of a new design has been made. In this design, the space inside the feeder becomes to be in the atomospheric pressure and the vacuum is sealed at the top of the feeder by using "o" rings. After this improvement, no serious damage to the feeder has occured.

The frequency range of the RF system has been limited to 7.5 MHz-17.5 MHz. The upper limit may be caused by the following characteristics of the resonator including the RF coupler. At a higher frequency, the input impedance is too samll to match the internal resistance of the power tube. The impedance increases as the capacitor of the RF coupler approaches to the dee. Unfortunately however, it is impossible, because undesirable discharges occur at the gap between the dee and the coupler.

At a lower frequency, the load impedance is large enough to match the internal resistance of the power tube. Such a high load impedance results in high grid current and high grid dissipation. Actually, the grid current exceeds the maximum rating. Moreover, the RF oscillation does not start easily. In order to overcome this situation, a resistance of the grid leak has been raised from 1 kΩ to 1.6 kΩ and a grounded capacitor (200pF) has been attached to the plate of the power tube in the case of the lower frequency.

3.3. Ion sources

A standard ion source of a hot filament type is used for light ions such as p,d, $^3He^{++}$and α, and is shown in Fig.3. The filament material has been recently changed from tantalum to wolfram, because a wolfram rod of 2 mm in diameter is available on the market. In heavier arc operation, for example, with 200 V and 1 A in arc voltage and current, a rather short life (10 hours) of the filament is observed and is a problem on the ion source still to be solved.

A heavy ion source of a cold cathode PIG type has been developed. It is shown in Fig.4. Table 1 shows the heavy ion beams obtained by this source. Typical working point of the pulsed arc discharge in a 33% duty cycle operation is, for example, 150 V and 7 A in average arc voltage and current for the production of $^{20}Ne^{6+}$ ions. The cathode life is 4 - 14 hours. Unfortunately, the base insulater of alumina was destroyed in a recent run. This damage was supposedly caused by mechanically weak points of the alumina.

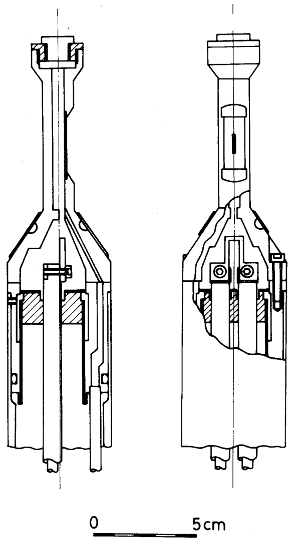

Fig. 3 Sectioned views of the ion source of a hot filament type

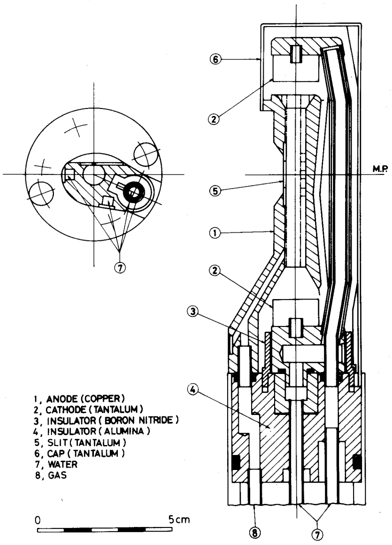

Fig. 4 Sections through the heavy ion source of a cold cathode PIG type

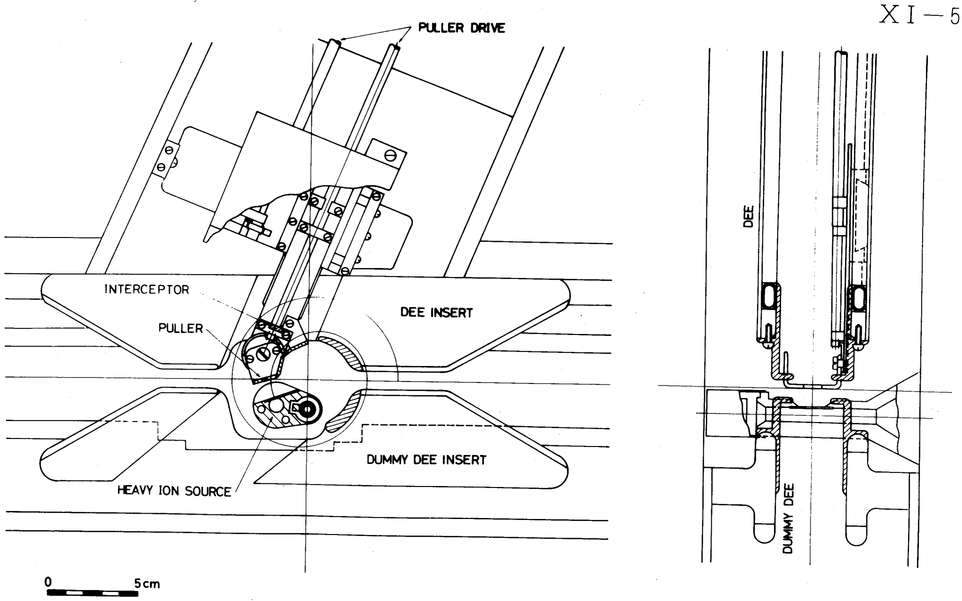

Fig.5 Layout of the central region for an internal ion source

3.4. Central Region

The initial structure of the central region has been reported in the paper4). A gap between the dee and the dummy dee was 42 mm even at the central region and very wide. Such a structure was recongnized to be inadequate, especially in the 3rd harmonic acceleration of heavy ions, from the fact that the obtained beam intensity of $^{14}N^{4+}$ ions in the 3rd harmonic mode was less than that of $^{14}N^{5+}$ions in the fundamental mode. The wider gap is considered to affect severely the ion path in the 3rd harmonic acceleration.

A new central region has been designed and installed. Fig. 5 shows the improved central region. The dee-and dummy dee-inserts make a gap narrower and shield the initial ion path from the RF field. After the improvement, a reasonable beam intensity has been obtained in the 3rd harmonic acceleration of heavy ions. An improvement on the puller system has been continued; the base of the puller slit was cooled with a forced water and an interceptor of the unwanted beam was set on the base.

3.5. Beam extraction

The beam extraction system consists of two electrostatic deflectors. Parallel plates and quadrupole type electrodes were chosen for the first and second deflectors, respectively. In our design, the septum electrodes are isolated and we can measure septum current.

The extraction efficiency through two deflectors is 40 - 60%.

In August of 1976, a damage of the septum of the first deflector occured. Entrance of the septum has a V-slot structure of 0.2 mm thickness and it melted. Several holes were also opened on the septum. At that time, the septum current was not limited in the cyclotron operation. Since then, we have operated in the restricted maximum septum current of 4 μA. Recently, we examined the septum and a slight damage was noticed at the entrance of the septum. So the limited value of 4 μA is considered to be reasonable.

Considering the extraction efficiency of the beam deflector system and the restriction on the septum current, intensity of the extracted beam will not be increased so much. Now, a deflector system of a new design has been designed and is under construction.

3.6. Beam diagnostic elements

Three beam probes can be used at the same time; dee probe, deflector probe and main probe. The dee and deflector probes are of a differential type. The main probe is used as one of the four types of differential, three fingers, phase and beam stopper. In a standard service of the cyclotron, the main probe is operated as the beam stopper.

Beam emittance of the extracted beam is measured by using the emittance measuring device5), which is placed at the initial stage of the beam transport system. Recently, the device is connected to the computer TOSBAC-40C for quick measurement and analysis.

3.7. Operation

The ion source and the puller are set at the calculated positions. The position of the ion source is adjusted by rotating its own axis so that the beam becomes maximum. Currents of the trim coils are, in principle, set to the calculated value. But currents of the most inside and outside trim coils are adjusted by operators. In order to obtain the maximum beam current , operators adjust the following other parameters; position of the center plug, currents of the valley and harmonic coils, positions of the septum and deflector, and the deflector voltage. Dee voltage is fixed to a calculated value, which depends upon the energy, the kind of the particle and the turn number.

4. Beam Transport System

4.1. Achromatic beam transport

Beam analyzing system of the high resolution courses consists of two quadrupole and two dipole magnets. These are arranged in order of QDDQ. This system cannot be operated in a doubly achromatic mode, while it can work in a singly (image) achromatic mode. In recent experience of the achromatic operation for the heavy ion beam, it was found that the beam energy resolution became worse when slits of the beam transport system were made narrower. This effect is supposedly due to a slit scattering.

REFERENCES

1. Y. Hirao et al., Seventh International Conference on Cyclotrons and their Applications (Zürich, 1975) p.103
2. Y. Hirao et al., ibid., p.312
3. M. Fujita et al., Proc. of this Conference, 24Ca7
4. INS Annual Report 1974, p.5
5. T. Honma et al., Proc. of this Conference, 23Ap2