STATUS OF THE INS 176cm SECTOR FOCUSING CYCLOTRON

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Abstract

The INS SF cyclotron is a multi-particle variable-energy accelerator and has been in operation since 1974. The maximum energy usable for experiments is 35 MeV for protons, 34 MeV for deuterons, 90 MeV for $^{3}\mathrm{He}$ and 68 MeV for α-particles. Up to 8 μA of these beams are extracted. A cold cathode PIG source for heavy ions was developed and extracted beams of 4.3 μA $^{14}\mathrm{N}^{5+}$ and 1.5 μA $^{20}\mathrm{Ne}^{6+}$ are obtained. Polarized protons are axially injected and about 15 nA are deflected.

The beam transport system consists of low, medium and high resolution courses. Eleven target stations are available for experiments and eight of them are ready for use. The high resolution course is a double monochrometer system, which can also be operated in a non-dispersive mode.

This paper describes the beam development since routine operation started.

1. Introduction

The design, construction, performance and operation of the INS SF cyclotron and the beam transport system have been reported in refs. 1) and 2). Since the last conference, efforts have been made to accelerate various kinds of ions to various energies and to improve the reliability of the cyclotron. The machine has been continuously operated and used for nuclear physics experiments with the exception of a few unscheduled shutdowns. One of these was caused by a trouble in the alumina insulator of the rf coaxial feeder, which was soon replaced by a new type. Others were due to the exchange of the septum electrode, which melted in an operation of a high beam intensity.

2. Beam Performance

Table 1 shows the usable energy and typical intensity for various kinds of ions. The maximum intensity of the external beam has been limited to about 8 μA, which is a compromise between the extraction efficiency and the power dissipation at the septum electrode.

The energy spread of the extracted beam was measured by using the beam analyzing magnets of the double monochrometer system. It was found that the energy spread of the extracted beam is about equal to the energy-gain per turn and lies in the order of $\Delta E/E \sim 3\times10^{-3}$(fwhm). In the dispersive mode of the double monochrometer system, it is possible to filter the energy resolution of the beam to 1.4×10^{-4} and at the same time about 2% of the extracted beam can be transmitted to the target with a beam spot size of 1.5 mm(W) × 2.5 mm(H). In the case of medium energy resolution (about $2\sim3\times10^{-4}$), 8 to 10% of the extracted beam can be transmitted to the target (up to 0.6 μA) of the magnetic spectrograph. The system can be also operated in a non-dispersive mode and about 25% of the extracted beam is obtained with a beam spot size of 2.6 mm(W) × 5.2 mm(H).

The design value of the maximum energy has been achieved except for protons, whose goal is 48 MeV while the achieved energy is up to 35 MeV. The restriction is mainly caused by the limited range of the radio frequency presently available.

3. Heavy Ion Source

A standard ion source of a hot filament type is used for light ions such as p,d, $^{3}\mathrm{He}^{++}$ and α. A cold cathode PIG source has been constructed for production of multiply charged heavy ions. The ion source and

	Goal	Status (July, 1978)	
Ion	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
$^{12}\mathrm{C}^{4+}$	9* - 88	88	3.5 μA
$^{14}\mathrm{N}^{4+}$	10* - 76*	40*	5.0 μA
$^{14}\mathrm{N}^{5+}$	- 118	115	4.3 μA
$^{16}\mathrm{O}^{5+}$	11* - 103	103	4.5 μA
$^{16}\mathrm{O}^{6+}$	- 153	129	0.23 μA
$^{20}\mathrm{Ne}^{5+}$	14* - 83*	60*	0.10 μA
$^{20}\mathrm{Ne}^{6+}$	- 119	115	1.5 μA
$^{20}\mathrm{Ne}^{7+}$	- 162	150	0.02 μA

* 3rd harmonic acceleration

Table 1 INS SF cyclotron beams

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arc pulser power supply were essentially copied from the original Berkeley type[3),4)]. Fig.1 shows the ion source and Table 1 shows the characteristics of the heavy ion beams. Typical working point of the pulsed arc discharge for production of $^{20}Ne^{6+}$ ions is 150 V and 7 A in average arc voltage and current in a 33% duty cycle operation with a 1 ms pulse length and 3 ms pulse period. The cathode life ranges 4 ∿ 14 hours.

In the initial design, the top and bottom cathode holders were connected with a stainless steel water-cooled tube, which was wrapped with a thin tantalum foil. The life of the tantalum foil was relatively short and replacement with a new foil was troublesome. The tube has been changed to a tantalum tube, which was welded to cathode holders by a method of the electron beam welding. After this improvement, the tube and the cathode holders have been running stably, even for long arc operation. In a recent run, damage to the cast alumina base insulator took place. This was apparently caused by long term fatigue. Since it was not easy to change the insulator in the initial design, we have designed a new type of base insulator which is easily exchangeable. This is under construction.

4. Central Region

In the initial design of the central region, the gap between the dee and the dummy dee was 42 mm[1)] even at the central region. Such a structure has been recognized to be inadequate, especially in the 3rd harmonic acceleration of heavy ions. It was found that the accelerated 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 was designed and installed. Fig.2 shows the improved central region. The dee and dummy dee-inserts make the acceleration gap narrower and shield the initial ion paths from the rf field. The copper base of the puller slit was cooled with forced water and an interceptor of the unwanted beam was set on the base. With this central region, the beam intensity in the 3rd harmonic acceleration has been increased reasonably.

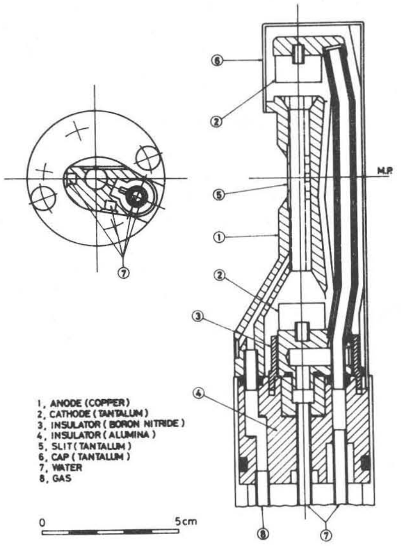

Fig.1 Sections through the heavy ion source of a cold cathode PIG type

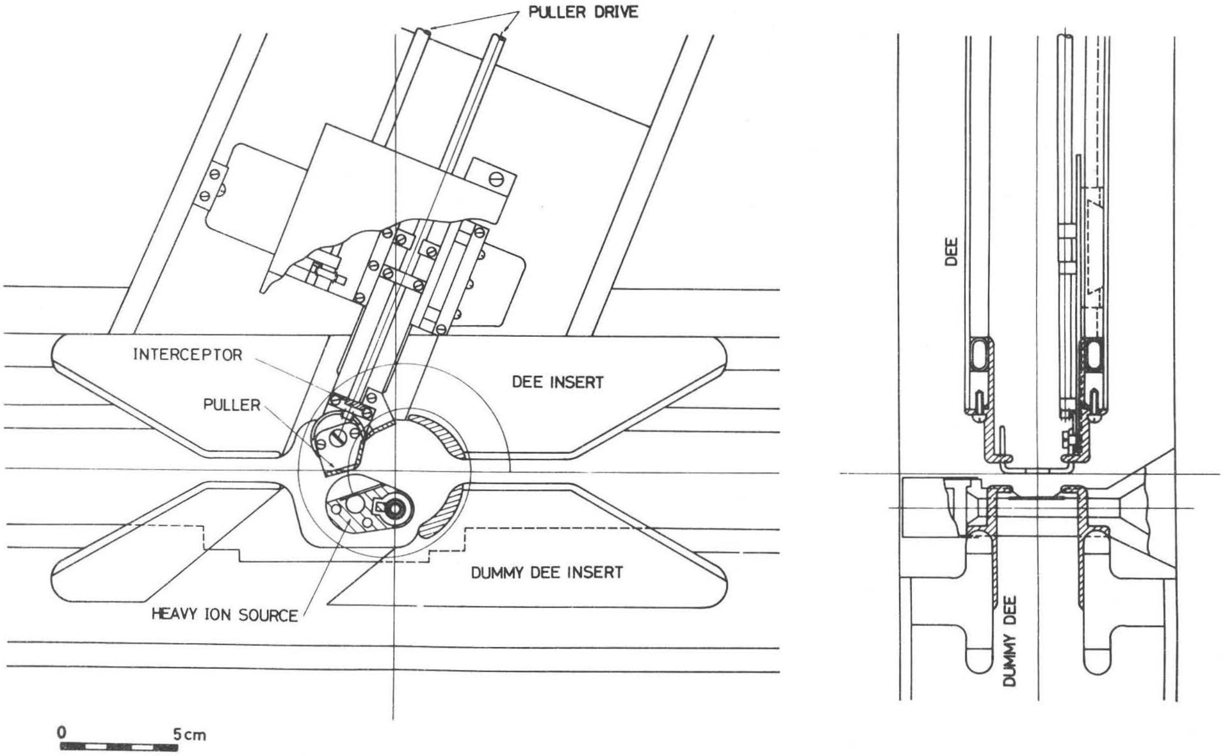

Fig.2 Layout of the central region for an internal ion source

5. On-line Data Analysis of the Beam Emittance

A device for beam emittance measurement consists of a first slit with 0.5 mm width and an ionization chamber with a second slit of the same width. The two slits are separated by a distance of two meters. The device is located just outside the cyclotron.

The beam density distribution was presented on a XY-recorder. However, the response of the XY-recorder was rather slow and acquisition of all the data took about 4 min. Furthermore, the phase space contour and the beam paths were drawn by hand afterward from the raw data. This work took a long time and was troublesome. In order to obtain the information on the extracted beam more quickly, a data processing system has been added to the device by using an on-line computer, TOSBAC-40C.

Fig.3 shows a block diagram of the system. The measuring procedure is as follows for one of the two directions, horizontal and vertical. At a given position of the first slit, the ionization chamber sweeps automatically across the beam pipe and measures the beam current through the second slit. Then the position of the first slit is shifted also automatically to the next position, and the above measurement is repeated. These procedures come to an end after the beam currents have been measured at the 16 positions of the first slit, yielding a set of raw data. The automatic cycling is controlled by hardware in the emittance measuring device. It is shown as the position programming unit in Fig.3.

Three signals are produced in the device; two analog voltages proportional to the positions of the first and second slits, and an analog voltage proportional to the current measured by the ionization chamber. The three signals are fed into three AD converters, which sample the three voltages according to the given gating signals produced by a pulse generator. The digitized data are stored in the memories of the computer. At a position of the first slit, 256 data are sampled, corresponding to 256 positions of the second slit. After this data acquisition process is completed, the operator can select one of the display modes through the TTY key-in. The display can be made on either one of the two output peripherals of the computer, the CRT and the digital XY-plotter. A profile of the current distribution, a phase space contour and beam paths can be displayed.

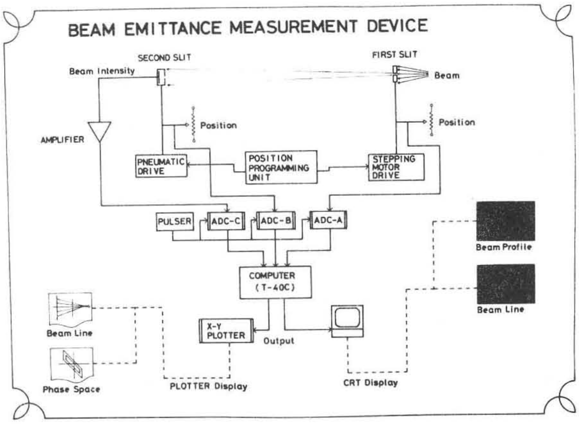

Fig.3 Block diagram of the system for the beam emittance measurement

The on-line computer system enables us to make a quick measurement of the character of the extracted beams. A whole set of raw data can be taken within a minute. This device is playing an important role in the diagnostics of the cyclotron and is expected to help the user achieve efficient beam transport to the target.

6. Internal Beam Behavior and Beam Extraction

The radial distribution of the beam current, the shadow shapes of one probe observed by another, and the phase width of the internal beam have been measured. Time structure of the internal beam was also measured with the rf-γ timing method[5].

The radial density distribution is reduced to radial betatron oscillations with a similar method to that used in the Karlsruhe Isochronous Cyclotron[6]. The equilibrium orbit at a given number of turns, K, is assumed to be

$$r_{eK}^{2} = A(K+K_0) - BK^2,$$

where A, K_0 and B are the parameters. In the first order approximation, the parameter A should be;

$$A = 2qV_D / m\omega^2 .$$

Fig.4 shows the radial betatron oscillation versus the number of turns. Unfortunately, individual turns cannot be distinguished over the total range of radii; they can be identified up to 155 turns whereas the cyclotron was set for about 250 turns to the extraction radius. In this case, the value of the parameter A is consistent with the above expression within 2%.

The phase width measurements are made according to the Garren and Smith formula[7]. The total width of the phase measured at the extraction radius is about 50 degrees.

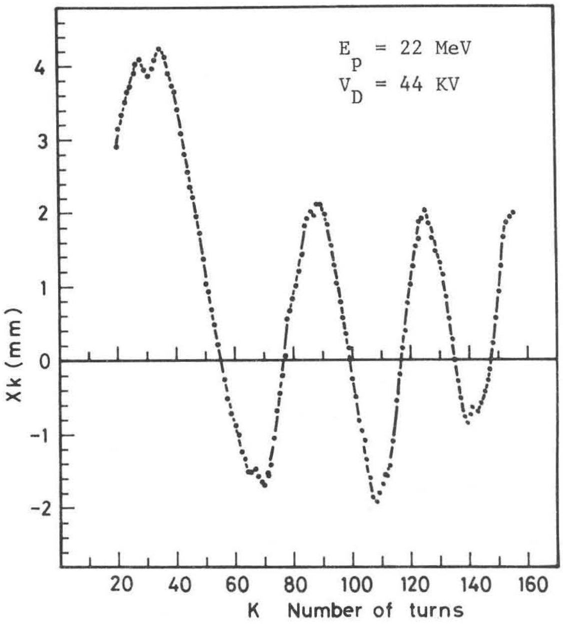

Fig.4 Radial betatron oscillations versus number of turns, where $x_K = r_K - r_{eK}$.

A beam burst width of the internal beam is measured by detecting reaction gamma rays at the beam probe with an organic liquid scintillator. A timing signal derived from the photomultiplier is used to start a time-to-amplitude converter (TAC), which is stopped by a signal of the cyclotron rf. The time width of 15 MeV protons is about 3.5 ns(fwhm) for operation at 11.5 MHz. This is about 15° with respect to the cyclotron orbit.

In the shadow shape measurements, the shadow shape of the entrance of the septum electrode was observed. Fig.5 shows the radial density distribution near the extraction radius. In the range of radii from 691 mm to 714 mm, the probe observes the shadow of the septum. When the currents of valley coils and harmonic coils are varied, the density distribution at these radii changes slightly and the energy distribution of the external beam varies also.
The five separate turns are identified at these radii in Fig.5. This suggests that five turns are extracted at the same time. Such a multi-turn extraction lowers the extraction efficiency of the deflector system and increases the power dissipation at the septum electrode.

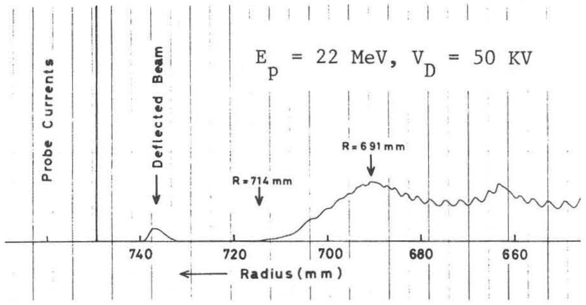

Fig.5 Radial density distribution near the extraction radius

The internal beam behavior presented above is unsatisfactory and should be improved. The initial ion path should be restricted with a few slits which restrict the phase and the emittance of the beam to be accelerated. The number of turns to extraction presently used ranges from 200 to 400. An arrangement of the central region can be easily varied according to the number of turns and can be easily varied without changing the dee and dummy dee inserts even for the axial injection of ions. Such a wide flexibility of the present central region is very useful but inadequate to get better beam quality, because the initial ion path is not restricted severely. Narrow but movable slits will be added to the central region.

A better beam quality will be also achieved with automatic beam tuning which holds continuously the given condition of the machine parameters. The elements required for the purpose are being developed. These are a non-intercepting capacitive beam probe in the cyclotron, an automatically controlled current supply for the trim coil and a rapid measuring device for the energy distribution of the external beam. Preliminary tests on beam tuning suggested a useful tuning method, in which the beam phase is used for tuning the current of the most outer trim coil and the difference of the beam intensities between the right and left slits of the double monochrometer system controls the cyclotron dee voltage.

In order to increase the external intensity of the cyclotron beam, a new deflector system is under construction. It is essentially the same type as the present one but an entrance electrode of the first septum is made of a wolfram sheet, which can hopefully overcome the present limitation of 8 μA for the external current.

7. Future Developements

The plan of future developments calls for an increase of the maximum proton energy and construction of a new beam course for a heavy ion storage ring.

In order to get higher energy protons, the rf system will be improved. The present rf system consists of a self-oscillator which is connected to a dee voltage stabilizer in series to the power supply1). At radio frequencies above 17.5 MHz, the plate load impedance is too low to be matched with the internal resistance of the power tube (9T71A). The power tube presently used should be replaced by a more powerful one and at the same time a MOPA system is to be constructed because of its many advantages over the self-oscillator system. The MOPA system is also suited for injecting heavy ions from this cyclotron to a storage ring which is under construction. It is a test ring of the Numatron project8), which is a high energy and high intensity heavy ion facility at the INS. High stability of the radio frequency system realized with an MOPA method is necessary for a precise timing in accumulating the beam in a storage ring.

A new beam course to the storage ring is to be constructed in place of the present course 2B-3. The course has been designed to inject the beam to the storage ring in a doubly achromatic mode after its energy is analyzed up to about 10^{-3}.

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