

STATUS OF INJECTOR AVF CYCLOTRON AT RIKEN

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Abstract

A K70 AVF cyclotron, which is used as an injector of the K540 RIKEN Ring Cyclotron (RRC) for light and light heavy ions, was completed at the end of March 1989. The first beam of  $^{14}\text{N}^{5+}$  ion with 7 MeV/u, the designed maximum energy, was successfully extracted from the cyclotron in April. The beam was injected into RRC and the  $^{14}\text{N}^{7+}$  beam of 135 MeV/u corresponding to the maximum magnetic rigidity of RRC was extracted in July. The cyclotron is now satisfactorily in routine operation. A brief description of the cyclotron is given and some operational experiences obtained in the last half-year operation are presented.

Introduction

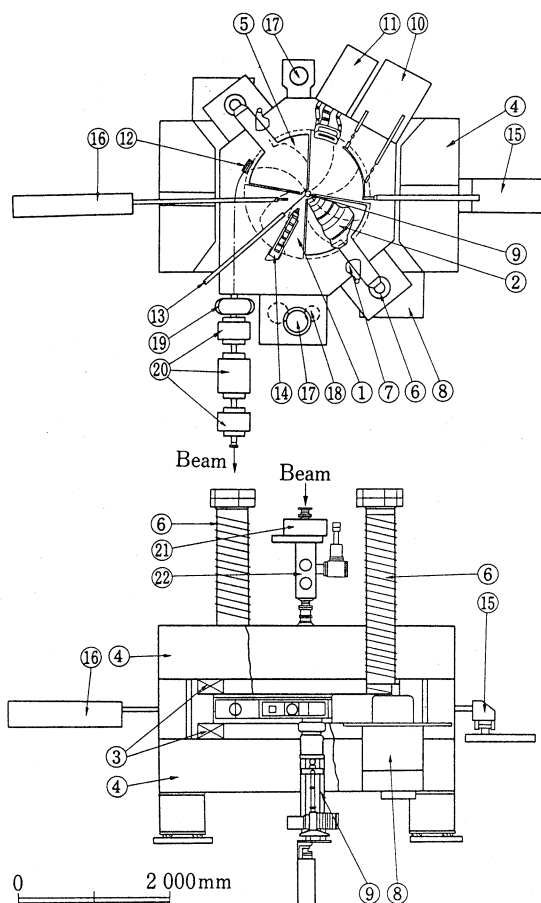
The AVF cyclotron is designed so as to be used mainly as an injector of the RIKEN Ring Cyclotron (RRC), which has been in routine operation<sup>1</sup> since 1987 coupled with RILAC for heavy ions, in order to get high energies for light and light heavy ions. In coupled use with RRC, the final energies designed are 210 MeV for protons, 135 MeV/u for  $^{12}\text{C}$ ,  $^{14}\text{N}$  and  $^{16}\text{O}$ , 95 MeV/u for  $^{40}\text{Ar}$  and so on.

The cyclotron was completed at the end of March 1989. We then successfully extracted the first beam of  $^{14}\text{N}^{5+}$  ion with 7 MeV/u in April. After some machine study of the cyclotron, in July we transported the ion to RRC after charge stripping and succeeded in accelerating and extracting it with 135 MeV/u, its top energy. Routine operation started in October, and so far upon coupling with RRC two kinds of ion species, 135 MeV/u  $^{14}\text{N}^{7+}$  (7 MeV/u  $^{14}\text{N}^{5+}$ ) and 102 MeV/u  $^{18}\text{O}^{8+}$  (5.5 MeV/u  $^{18}\text{O}^{6+}$ ), have been used for experiments.

Description of the AVF cyclotron

Figure 1 shows a schematic drawing of the cyclotron. This cyclotron is a type 750PV<sup>2</sup> of Sumitomo Heavy Industries, Ltd. (SHI), modified so as to be used as an injector of RRC. Performance of the cyclotron is shown in Fig.2. It has a K-value of 70 and can accelerate ions whose m/q value is up to 4. Details of the cyclotron was reported elsewhere.<sup>3</sup>

The magnet is of the H-type with four spiral sectors. Pole diameter was chosen to be 1730 mm by taking account of the extraction radius of 714 mm, which was determined from the matching condition to RRC. Nine pairs of circular trim coils are wound on



- ① Sector pole
- ② Trim coil
- ③ Main coil
- ④ Yoke
- ⑤ Dee
- ⑥ Resonator
- ⑦ Compensator
- ⑧ Oscillator
- ⑨ Infector
- ⑩ Deflector
- ⑪ Magnetic channel
- ⑫ Gradient corrector
- ⑬ Phase slit
- ⑭ Phase probe
- ⑮ Extraction profile monitor
- ⑯ Main radial probe
- ⑰ Cryopump
- ⑱ Turbomolecular pump
- ⑲ Steerer
- ⑳ Quadrupole magnet
- ㉑ Solenoid
- ㉒ Emittance monitor, Faraday cup, Profile monitor, Beam buncher

Fig. 1. Schematic drawing of the AVF cyclotron.

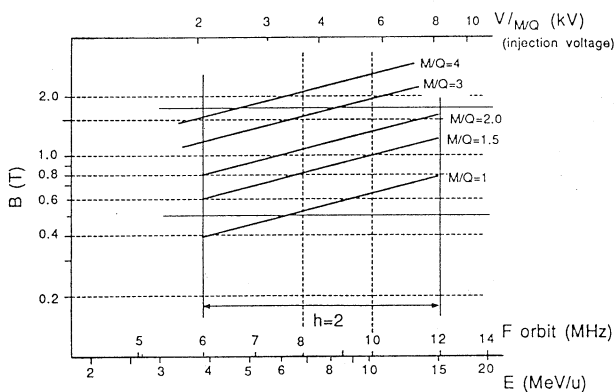


Fig. 2. Performance of the AVF cyclotron.

the sectors and four pairs of harmonic coils are placed in the extraction region of valley sections. The maximum average field is 1.7 T.

Two-dee system with a dee angle of  $85^\circ$  is adopted. The resonator is of the  $\lambda/4$  coaxial type with a movable shorting plate. The coaxial part is perpendicularly connected to the dee plate (SHI patent) as shown in Fig.1. The frequency range is 12-24 MHz (the acceleration harmonics equals 2) and the required voltage is 50 kV at the maximum. The power amplifier system consists of a 500 W solid-state wide-band amplifier and a grounded-cathode tetrode amplifier (EIMAC 4CW50,00E). An all-pass network is adopted in the input circuit of the tube. The combination of the wide-band amplifier and the all-pass network system was adopted because of easiness for operation and maintenance.

An electrostatic inflector is used to bend a beam onto the median plane of the cyclotron. The inflector is of the spiral type whose electric radius and magnetic radius are 26 mm and 16.3 mm, respectively. The gap between two copper electrodes is 5 mm and voltages of up to  $\pm 5$  kV are fed to the electrodes. The inflector is inserted through the hole of the lower yoke. It can be rotated by  $5^\circ$  and can be adjusted vertically by  $\pm 5$  mm.

One of the most significant changes from the 750 PV is that with respect to the central region of the cyclotron. The layout of the central region is shown in Fig. 3. Pillars are placed at the first two gaps. The nose part of the electrode in this region is remountable for maintenance or repair. A movable phase defining slit is set on the first turn inside the dummy dee. The position and the gap of the slit are remotely movable by 10 mm each.

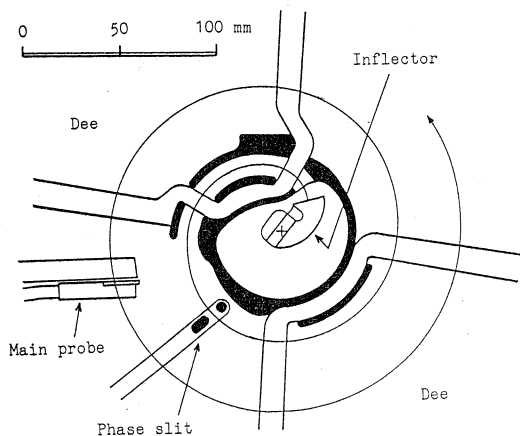


Fig. 3. Schematic drawing of the central region of the cyclotron.

A beam is extracted by means of an electrostatic deflector and a magnetic channel. After the magnetic channel a gradient corrector of a passive type is placed to focus a beam radially. The positions of the deflector, the magnetic channel and the gradient corrector can be remotely controlled by 15, 10 and 16 mm, respectively.

As shown in Fig. 1, a main radial probe, a deflector probe and phase probes are placed inside the cyclotron for beam diagnostics. The main probe is inserted through the hole of the side yoke. The probe head has three finger-like electrodes for the differential measurement and an electrode for the integral measurement. An orbit pattern near the extraction can also be measured with the deflector probe in front of the entrance of the deflector. Its stroke is 100 mm. The phase probes are used to measure the relative phases of beams on different turns. They are made of parallel plates of glass epoxy on which six pairs of rectangular pickup electrodes are formed by coating solder. These phase probes are very helpful to get an isochronous field. In front of the entrance of the inflector a baffle slit divided into four leaves is placed to get information on whether a beam clears the element or not. A baffle slit vertically divided into two is placed in front of the electrode of the deflector, and that horizontally divided into two is attached to the entrance of the magnetic channel and the gradient corrector.

Two cryopumps of 6,500 and 4,000 l/sec and a turbo-molecular pump of 1,500 l/sec are used to evacuate the chamber.

External ion sources such as an ECR source<sup>4</sup> and a duoplasmatron are used for this cyclotron. Beams from these ion sources, which are situated in the room over the cyclotron vault, are injected axially through the hole of the upper yoke. Two Glazer lenses and a steerer are placed inside this hole.

A beam buncher is placed at 2 m upstream from the inflector. The buncher has a single gap formed with two meshes, one of which is excited by an optimal combination of  $f_0$ ,  $2f_0$  and  $3f_0$  giving a sawtooth-like wave.<sup>5</sup> The maximum required voltages are 380, 230 and 80 V for  $f_0$ ,  $2f_0$  and  $3f_0$ , respectively. This is expected to make the bunching efficiency significantly high.

All the system of the cyclotron is remotely controlled and monitored by means of the same computer control system as that of RRC.<sup>6</sup>

#### Operational performance

We injected a beam from the ECR source into the AVF cyclotron and succeeded in extracting the first beam from the cyclotron in April 1989. The ion accelerated was 7 MeV/u  $^{14}\text{N}^{5+}$ . Up to now two kinds of ion species, 7 MeV/u  $^{14}\text{N}^{5+}$  ion and 5.5 MeV/u  $^{18}\text{O}^{6+}$ , have been accelerated and routinely used for experiments upon coupling with RRC. Characteristic features experienced in the last half-year operation are given in the following:

**Isochronization** - Signals from six pairs of non-destructive phase probes indicate that after the initial setting a fine adjustment of only main coil current can give phase excursion of less than  $\pm 5^\circ$ . By further adjustment with a particular trim coil's current, we can easily get nearly ideal isochronous field.

**Compression factor with a beam buncher** - A single gap buncher producing a sawtooth-like wave by an optimal combination of  $f_0$ ,  $2f_0$  and  $3f_0$  provides a good compression factor of 5 to 6.

**Transmission** - Ratio between the currents before injection and after extraction is 20 to 30 % at a typical beam current of several  $\mu\text{A}$ . It is noted that in this case part of the beam is cut with a slit at the upstream of the cyclotron.

**Single turn extraction** - A beam profile measured with a profile monitor placed downstream of the cyclotron indicates that the single turn extraction can be

achieved by careful tuning.

**Stability** - The cyclotron has been operated in a very stable condition. Retuning of the cyclotron, mainly readjustment of the main coil current, is necessary at most once in one-week operation, despite that the stability required for the coupled operation with RRC is severe.

**Reliability** - The tuning of the machine including the beam transport can be completed by a slight adjustment of the parameters that are determined in the previous run. The isochronous field distribution is reproduced quite well in every run.

**Vacuum pressure** - A pressure of  $1 \times 10^{-5}$  Pa is achieved with two cryopumps of 4000 and 6500 l/s.

Figure 4 shows an example of beam orbit pattern measured with the main radial probe for the  $^{14}\text{N}^{5+}$  beam. An example of beam orbit pattern measured with the deflector probe is shown in Fig. 5.

Although the cyclotron has worked successfully as mentioned above, there are still some open problems. They are:

- Beam pattern measured with the radial probe is slightly different from the calculation.
- Extraction efficiency is not so good (typically 60 to 70 %) despite that the beam separation at extraction is quite enough for single turn extraction.
- Transmission of a beam of high intensity (several tens  $\mu\text{A}$ ) that is delivered when a slit at the upstream of the cyclotron is fully open is less than 10 %. We expect that this is due mainly to insufficient tuning of the injection beam transport.

#### Acknowledgements

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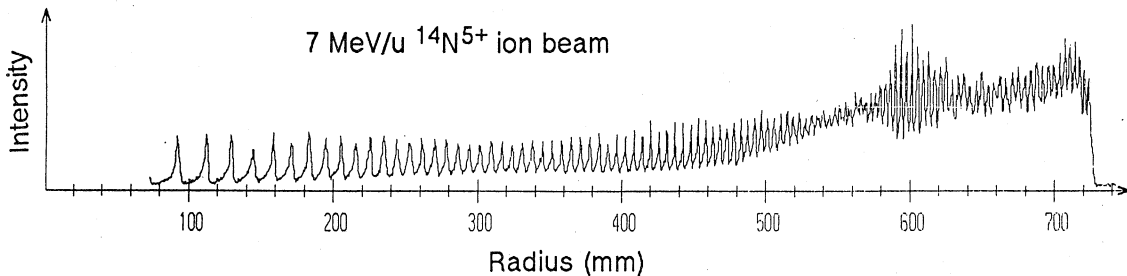


Fig. 4. Example of orbit pattern of 7 MeV/u  $^{14}\text{N}^{5+}$  ions measured with the main radial probe. The number of revolutions is about 110.

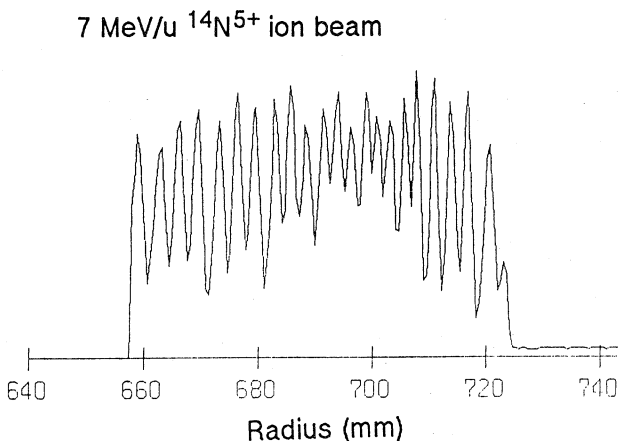


Fig. 5. Example of orbit pattern of 7 MeV/u  $^{14}\text{N}^{5+}$  ions measured with the deflector probe. A small peak adjacent to the final orbit peak shows that in this case single turn extraction is not achieved. This small peak disappears by fine tuning, for example by adjustment of the dee voltage.

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