CONSTRUCTION AND PRESENT STATUS OF THE JAERI AVF CYCLOTRON

K.Arakawa, Y.Nakamura, W.Yokota, M.Fukuda, T.Kamiya, T.Nara,
T.Agematsu, S.Okumura, I.Ishibori, R.Tanaka, and M.Maruyama.

Takasaki Radiation Chemistry Research Establishment,
Japan Atomic Energy Research Institute,
1233 Watanuki-machi, Takasaki-shi, Gunma-ken, 370-12, Japan
and
T.Tachikawa, Y.Hayashi, K.Ishii, and T.Satoh

Sumitomo Heavy Industries, Ltd.,
5-2 Soubiraki-cho, Niihama-shi, Ehime-ken, 792, Japan

Abstract

The JAERI AVF cyclotron has been constructed since 1988. The first beam, 50MeV $^4He^{2+}$ ion, was successfully extracted from the cyclotron in March, 1991. The present report outlines the cyclotron system and shows some results in the first operation.

Introduction

Takasaki Ion Accelerators for Advanced Radiation Applications (TIARA) including an AVF cyclotron have been constructed at the Takasaki Radiation Chemistry Research Establishment of the Japan Atomic Energy Research Institute (JAERI)[1]. The Advanced Radiation Technology (ART) project is intended to make effective use of the characteristics of ion beams and their interactions with matter for R & D on materials for space environment and nuclear fusion reactors, and for research on biotechnology and new functional materials.

The JAERI AVF cyclotron is of the model 930 (K=110 MeV) of Sumitomo Heavy Industries, Ltd. (SHI) and is basically the same model as those of The National Institute of Radiological Science in Japan , Universite Catholique de Louvain and Institut National des Radioelements in Belgium. In order to meet technical requirements in research programs of the ART project, we modefied or improved the design of the accelerator system as follows; (1) The cyclotron system is equipped with two external ion sources, an ECR source for generating heavy ions and a multicusp source for generating light ions. (2) The system is equipped with a beam chopping system for pulsed beam operation and a beam scanning systems for uniform irradiation to the wide area of target samples. (3) A distributed computer control system is introduced for rapid and reliable control of operation parameters, which results in improvement of the operational efficiency and flexibility.

The construction of the cyclotron started in 1988, the field mapping for the main magnet was carried out from December, 1988 to March, 1989 and the performance of the RF system was tested from October, 1989 to March, 1990 at the Niihama works of SHI. The cyclotron was installed at JAERI, Takasaki, in July, 1990. The beam generation test has been started from March 1991.

Outline of JAERI AVF cyclotron

Figure 1 shows a photograph of the cyclotron. The main characteristics of the JAERI AVF cyclotron are shown in Table 1. The original model of the cyclotron was equipped with an internal ion source, and then it was modified to allow axial injection from external ion source, resulting in complete separation of ion sources from cyclotron in beam operation and maintenance.

The cyclotron is a 4-sectored variable-energy AVF machine with an extraction radius of 923 mm. The acceleration electrodes consist of a couple of 86-degree dees, each connected with a resonant cavity. Movable-panel type resonators originally proposed for the model 930 were replaced by movable-shorting type ones generating a higher maximum acceleration voltage of 60 kV to extract 90 MeV protons. Beams of protons, deuterons and helium ions are available with maximum energies of 90, 53 and 108 MeV, respectively. Heavy ion beams can be accelerated to an energy range of 2.5xM MeV to $110xZ^2/M$ MeV (M:mass number, Z:charge state).

Magnet and magnetic field

The cyclotron magnet is of an H-type with a pole

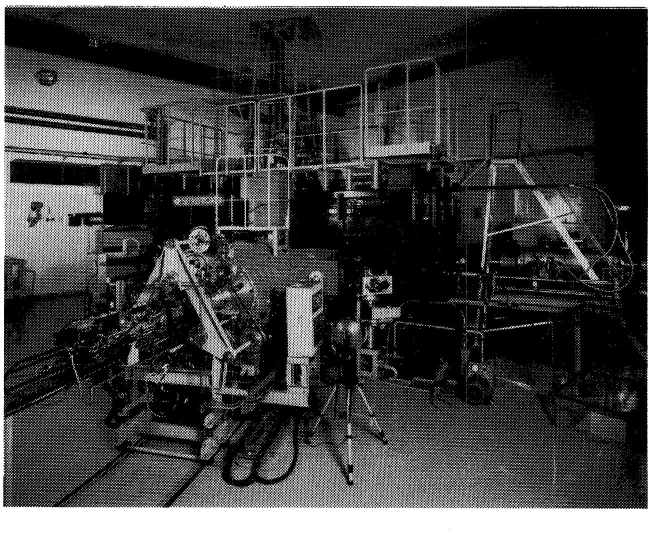

Fig.1 Photo of the JAERI AVF cyclotron.

Table 1 Characteristics of JAERI AVF cyclotron

Cyclotron		
K-value		110
Extraction radius		92.3cm
Number of secters		4
Number of dees		2
Dee angle		86°
Maximum dee voltage		60kV
RF range		10.6～22MHz
Resonator		Movable short type
Harmonic number		1,2,3
Range of M/Z		1～6.5
(M:mass,Z:charge state)		
Range of Acceleration Energy		
Light ion	H^+	5～90MeV
	D^+	5～53MeV
	$^4He^{2+}$	10～108MeV
Heavy ion	$2.5 \times M \sim 110 \times Z^2/M$ MeV	

diameter of 2156 mm and four spiral sectors. Twelve pairs of circular trim coils are wound concentrically on the sectors.Two sets of four pair harmonic coils are placed in the central and extraction region.

Maps of the base and the trim magnetic fields were measured[2]. The maximum field strength at the extraction radius is 16.7 kG. The strength of the first harmonic field was less than 4G within the extraction radius.

RF system

Two dee system was adopted with a dee angle of 86° . The resonator is of the λ/4 coaxial type with a movable shorting plate. The frequency range is 10.6 - 22 MHz and the maximum dee voltage is 60 kV. The details of the RF system is reported in a separate paper at this symposium[3].

Injection, Central Region, Extraction

Low-energy beams from the ion sources, located in the basement, are axially injected into the mediamplane of cyclotron upwards through the hole of the bottom yoke. Four Glazer lenses and a steerer are placed inside this hole. The layout of the axial injection system is shown in Fig.2.

The injected beam is guided to the median plane of the cyclotron through a spiral inflector and a puller, which are prepared separately for each acceleration harmonic number from 1 to 3. The inflector is inserted downward through the hole of the upper yoke.

The layout in the central region is shown in Fig.3. Two movable phase defining slits are set inside the dee and the dummy dee within the first turn. The beam extraction system consists of an electrostatic deflector and a magnetic channel and also of a gradient corrector to focus the beam horizontally. The either position of the deflector and the magnetic channel can be controlled remotely. The position of the gradient corrector of a passive type can be manually moved by ±20 mm.

Beam diagnostics

A main radial probe, a deflector probe, a magnetic channel probe and a set of phase probes are placed inside of the acceleration chamber of the cyclotron for beam diagnostics. The main probe is inserted through the hole of the side yoke and its stroke covers 1150 mm (R= 40 ~ 1190 mm). The main radial probe head provides three finger-like electrodes to measure the beam current differentially and integrally. An orbit pattern near the extraction can also be measured with the deflector probe

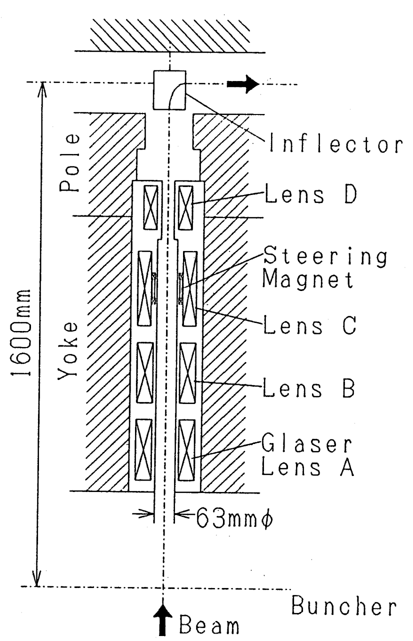

Fig.2 Layout of the axial injection system.

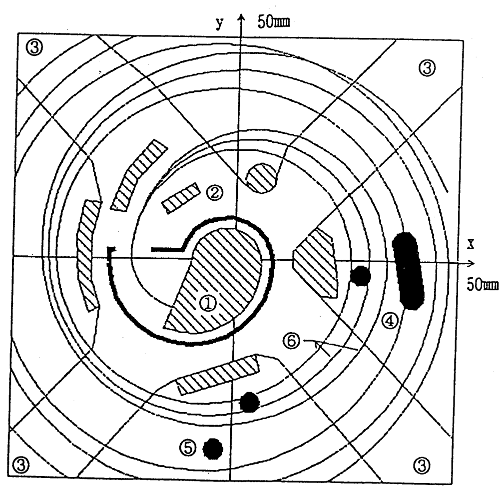

Fig.3 Schematic drawing of the central region of the cyclotron. (1) Inflector, (2) Puller, (3) Dee gap, (4) Phase slit II, (5) Phase slit I, (6) Beam trajectories (dee voltage 40,50 and 60 kV)

in front of the entrance of the deflector. The phase probes consist of ten pairs of rectangular pickup electrodes of copper to measure the relative phases of beams on different turns.

A buffle slit system consisting of four leaves is placed just before the entrance of the inflector to get information on whether a beam clears the element or not. Other two buffle slit systems are placed at the entrance of the magnetic channel and the gradient corrector. Another buffle slit system is also placed at the extraction hole of the vacuum chamber.

Ion source and injection beam line

Special care was taken for the injection transport system in order to carry ion beams with low energy, high intensity and large emittance along the beam line 17 m long. The geometry of the extraction electrodes for the multi-cusp type ion source was optimized for extraction with low voltage (~3 kV). A klystron type buncher with two gap and $\lambda/2$ mode is set at a distance of 1.5 m from the median plane of the cyclotron. A pulse voltage chopper (P-chopper) is also installed just before the buncher. The details of the ion sources and the injection beam transport system are also reported in a separate paper at this symposium[4].

Beam transport system

The layout of the beam transport system is illustrated in Fig.4. The system has eight main horizontal beam courses; four courses, LA ~LD, are for light ion beams, and the other four,HA ~ HD, are for heavy ion beams. It also has two horizontal branch beam courses, LE and HE, and four vertical branch beam courses, LX and HX ~ HZ. The focused beam diameter at the end of each beam course are estimated about 5 mmϕ from calculation of particle trajectories.

A beam chopping system[5] is installed to supply pulse beams with a wide ranges of pulse interval and acceleration energy, and a wide variety of ion species. A combination of the P-chopper of the injection line and a sinusoidal voltage chopper (S-chopper) at the exit of the cyclotron was adopted to extract a single pulse beam.

Uniform ion beam irradiation over wide area, within the maximum field size of 100 x 100 mm, will be available in a few beam courses . Two dimensional beam scanning with electromagnets was adopted for this system in consideration of high-intensity, high-energy ion beams.

Computer control system

The cyclotron system can be almost fully controlled by three mini-computers. In consideration of independence of each sub-system of the cyclotron, the computer system has three-stage hierarchy consisting of a system control unit (SCU;micro VAX 3500), group control units (GCU;rt-VAX 1000) and universal device controllers (UDC). The details of the computer control system is reported in a separate paper at this symposium[6].

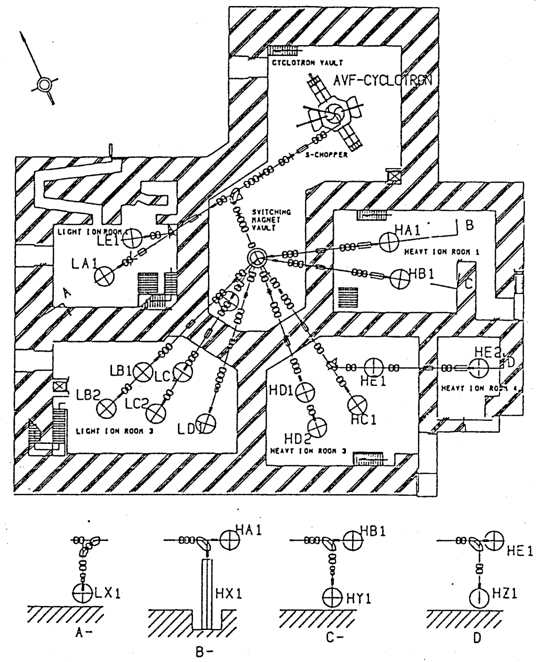

Fig.4 Layout of the beam transport system.

Results of first operation

The beam generation tests has been tried for H^+ (10, 45 and 90 MeV), D^+ (10, 35 and 50 MeV), $^{4}He^{2+}$ (20, 50 and 100 MeV), Ar^{8+} (175 MeV), Ar^{13+} (460 MeV) and Kr^{20+} (520 MeV) ions. Best transmission and extraction efficiency is 8.2 % and 65%, respectively. Transmission of low energy light ions (H^+ and D^+) in the injection system is rather influenced by beam intensity, which is a space charge effect.

A compression factor of above 2.5 or more has been achieved by the beam buncher with each harmonic acceleration mode. A single pulse beam (50 MeV He^{2+}) was successfully extracted by the beam chopping system at different interval times of 1.4 μs and 1 ms. Uniform beam irradiation over the wide area of 20 to 100 sq mm was achieved by the beam scanners.

The first beam operation for the experiments is scheduled in early time of 1992.

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