RF SYSTEM OF JAERI AVF CYCLOTRON

M. Fukuda, K. Arakawa, Y. Nakamura, W. Yokota, T. Kamiya, T. Nara,
T. Agematsu, S. Okumura, I. Ishibori, R. Tanaka, T. Karasawa
Japan Atomic Energy Research Institute
Takasaki, Gunma 370-12, Japan
and
A. Shimizu
Research Center for Nuclear Physics, Osaka University,
Mihogaoka, Ibaraki, Osaka 567, Japan
and
Y. Kumata and Y. Fukumoto
Sumitomo Heavy Industries, Ltd.
Niihama, Ehime 792, Japan

Abstract

A $\lambda/4$ coaxial type resonator with a movable shorting plate has been installed in the JAERI AVF cyclotron. A movable-panel type resonator originally proposed was replaced by the coaxial type resonator in order to make allowance for generating a higher maximum acceleration voltage of 60 kV, which is required for accelerating 90 MeV protons. The resonant frequency ranges from 10.6 to 22.0 MHz, and is finely tunable within a relative frequency $\Delta f/f$ of 1.6 %. The maximum peak dee voltage of 60 kV at 21.14 MHz is generated within a stability of $\pm 1\times 10^{-3}$.

Introduction

The JAERI AVF cyclotron(K-number=110)[1] has been constructed for the purpose of extensive application of ion beams to R&D for advanced radiation technology[2]. Various kinds of ions from proton to xenon in a wide range of energy are required for fundamental research in materials science and bio-technology. We have two types of external ion sources[3] in order to meet the requirement of producing light to heavy ions; one is a multicusp type ion source for generating proton, deuteron and helium ions, the other is an ECR type ion source[4] mainly for heavy ions from boron to xenon. The ions with M/Q=1～6.5 can be accelerated in a broad energy range: 5～90 MeV for proton, 5～53 MeV for deuteron, 10～108 MeV for $^4He^{2+}$ and $(2.5\times M)\sim(110\times Q^2/M)$ MeV for heavy ions, where M is mass number and Q is charge state. Acceleration harmonic numbers of 1, 2 and 3 are available.

The JAERI AVF cyclotron is of the model 930 of Sumitomo Heavy Industries, Ltd.(SHI). The cyclotron is basically the same model as the CYCLONE(Universite Catholique de Louvain, BERGIUM), the IRE cyclotron(Institut National des Radioelements, BERGIUM) and the NIRS-Chiba cyclotron[5](National Institute of Radiological Sciences, JAPAN). The latter three cyclotrons have a movable-panel type resonator with a RF peak voltage of 50 kV. A higher maximum acceleration voltage of 60 kV was required for accelerating 90 MeV protons. However, it is hard to generate the acceleration voltage of 60 kV by the movable-panel type resonator owing to limitation in the power loss on the stem. The asymmetrical structure of the cavity results in partial increment of a current density on the stem facing the tuning panel, causing thermal damage due to the local power loss. The final amplifier with large output power above 80 kW is required to generate 60 kV for the movable-panel type resonator. The $\lambda/4$ coaxial type resonator with a movable shorting plate was adopted for the JAERI AVF cyclotron. The coaxial type resonator has a higher Q-value because of symmetrical current density distribution, allowing relatively low output power of the final amplifier within 30 kW.

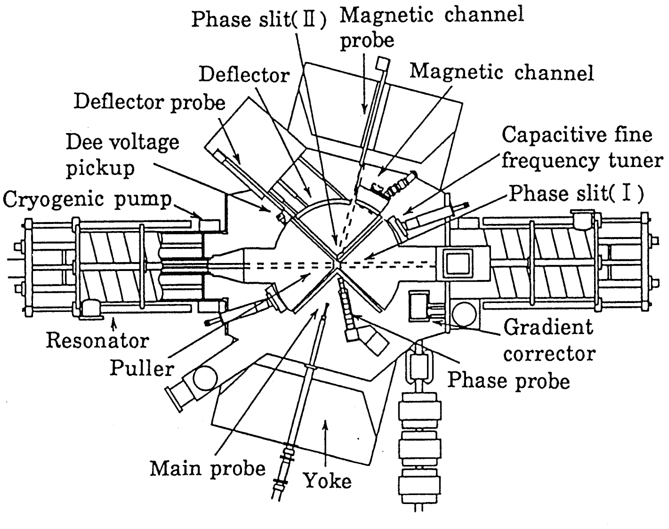

Fig. 1 Schematic drawing of the AVF cyclotron.

· The RF system was constructed by SHI. The geometrical structure of the coaxial type resonator has been designed on the basis of the one-dimensional transmission-line approximation calculation. Since there is no space for capacitive coupling of a power tube to the resonator around a dee electrode, the power tube is coupled inductively in the fore part of the cavity.

A 1/4 scale model cavity has been constructed in order to investigate the RF characteristics: resonant frequencies, Q-values, shunt impedances and effect of a capacitive fine frequency tuner. The results of the test agreed approximately with those expected and were useful for an actual design of the resonator.

RF cavity

A schematic drawing of the cyclotron is shown in Fig. 1 and the specification of the RF system is summarized in Table 1. Two dees with a dee angle of 86° are made of 10 mm thick oxygen free copper. Cooling water pipes lie on the inside surface of the dee. A puller electrode for extracting ions from an inflector is inserted in contact with the inner surface of one dee along the coaxial line of the cavity. One of two phase slits is also led through the inside of the other dee. The vertical aperture is 34 mm at the stem of the puller or the phase slit, and 40 mm

Table 1
Specification of the RF system

Number of dees	2
Dee angle	86°
Maximum dee voltage	60 kV
RF frequency	10.6 ~ 22.0 MHz
Resonator	Movable-short type
Harmonic number	1, 2, 3
Vertical aperture inside dee	40 mm
Gap between dee and ground plate	42 mm
Movable range of shorting plate	1350 mm
Inner tube diameter	300 mm
Inside diameter of outer tube	1000 mm
Full relative frequency change $\Delta f/f$	1.6 %
RF voltage stability	$< \pm 1\times 10^{-3}$
RF phase stability	$< \pm 0.5^\circ$
Pre-amplifier	EIMAC 4CW800B
Final amplifier	EIMAC 4CW50000E
Power feeder	inductive coupling
Maximum output power	50 kW×2

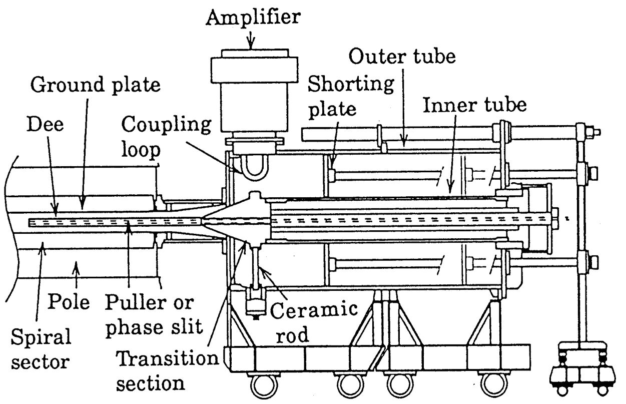

Fig. 2 Schematic view of the λ/4 coaxial type resonator with a movable shorting plate.

inside the dee. The gap between the dee and the ground plate is 42 mm. The ground plate is 2.5 mm thick copper plate with cooling water pipe. The acceleration gap in the central region is 17 mm and increases radially up to 56 mm at r = 920 mm. The capacitive fine frequency tuner made of oxygen free copper faces one end of the dee. The gap between the dee and the compensation plate of the tuner is automatically changeable from 8 to 50 mm. The dee voltage is monitored with a capacitive voltage pickup mounted on the lower ground plate by the other end of the dee. The amplitude of the picked up signal is about 1/1000 of the dee voltage.

A schematic view of the cavity is shown in Fig. 2. The dee is mounted on a transition section connected with an inner coaxial tube. The transition section, the inner and outer tubes are made of oxygen free copper. The transition section is supported by a vertical ceramic rod mounted on the outer tube. The inner tube is also supported at the end of the cavity. The inner tube with a diameter of 300 mm is of three-fold tube structure, consisting of two water cooling jackets and insertion space for the puller or phase slit. The inside diameter of the outer coaxial tube is 1000 mm. The cooling water pipes are wound on the outer surface of the tube. The outer tube can be axially separated into two sections for maintenance of the cavity. The shorting plate is in contact with both the inner and outer coaxial tubes by many sliding contact fingers made of silver-plated Cu-Be. The contacts are pressed on the wall of the tubes by pneumatic pressure. The movable range of the shorting plate is 1350 mm.

The final amplifier and the coupling loop is installed on the outer coaxial tube. The RF power is fed into the resonator over the transition section. The coupling loop made of 40 mm diameter copper pipe is cooled by water. A pair of cryogenic pumps(4000 L/s)^6 are mounted on the bottom of the coaxial tube, because there is no mounting space around the vacuum chamber of the cyclotron for the pumps. The head of each pump is covered with a mesh made of cooling water copper pipe to prevent overheating due to RF power leakage.

Electrical characteristics

Electrical characteristics of the resonator have been measured on low-level signals by using a network analyzer(HP-8753A). The low-level signals from the network analyzer was fed into the resonator at the coupling loop in parallel with the final amplifier. The dee voltage was monitored by the capacitive voltage pickup weakly coupled to the resonators. The shunt impedance was measured by perturbation method using a condenser coupled to the dee.

Resonant frequency of the resonators is shown in Fig. 3 as a function of position of the shorting plate. The frequency is changeable from 10.6 to 22.0 MHz within the movable range of the shorting plate. The gap dependence of the fine frequency tuner is shown in Fig. 4. The full relative frequency change Δf/f is 1.6 % at the gap of 50 mm. The best position for fine frequency tuning can be found within the tunable range.

The measured Q-value and the shunt impedance of the

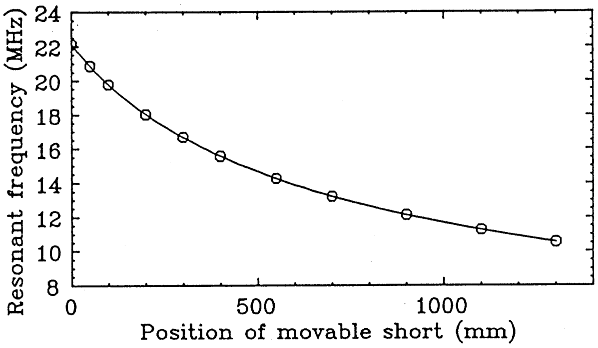

Fig. 3 Resonant frequencies of the resonator as a function of position of the movable shorting plate.

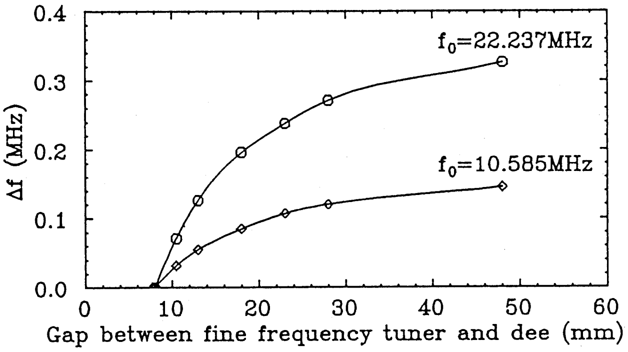

Fig. 4 Gap dependence of the fine frequency tuner at a resonant frequency of 22.237 and 10.585 MHz. The full relative frequency change Δf/f is 1.6 % at the gap of 50 mm.

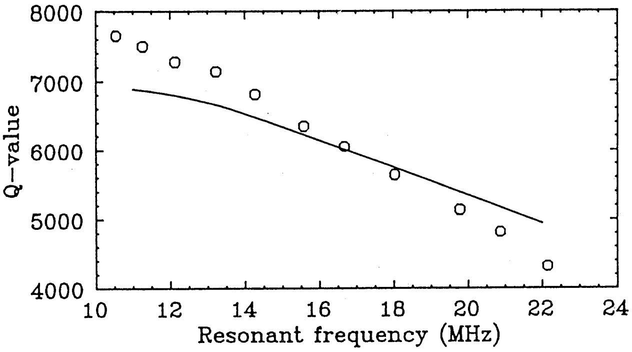

Fig. 5 Frequency dependence of Q-value. The solid line shows 80 % of the calculated Q-value based on one-dimensional transition-line approximation.

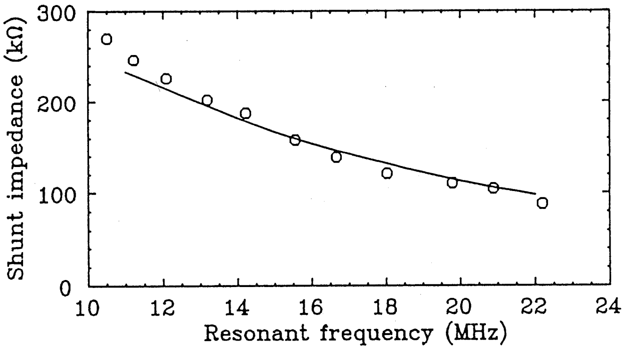

Fig. 6 Frequency dependence of shunt impedance. The solid line shows 85 % of the calculated shunt impedance based on one-dimensional transition-line approximation.

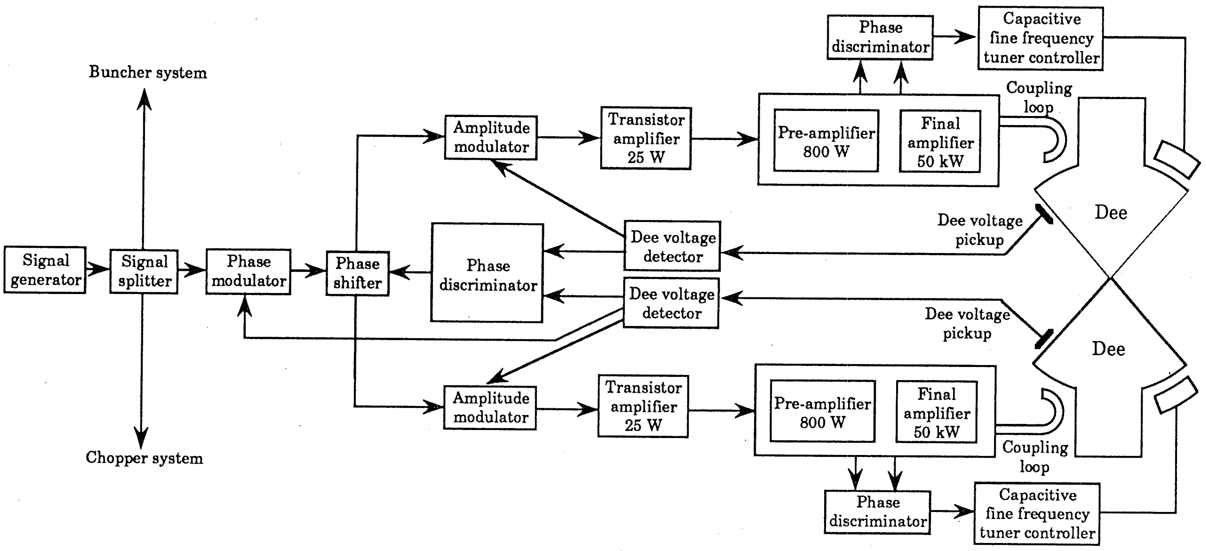

Fig. 7 Block diagram of the amplifier system.

resonator are shown in Fig. 5 and 6 as a function of the resonant frequency, respectively. The measured Q-values and shunt impedance are smaller than calculated ones, by 10 to 30 %, obtained by one-dimensional transmission-line approximation. The disagreement results from uncertainty in estimation of the capacitance and resistance due to the complicated structure of the resonator. However, the frequency dependence of the Q-value and the shunt impedance are roughly reproduced by the calculation.

Amplifier system

A block diagram of the amplifier system is shown in Fig. 7. A synthesized signal from a signal generator(HP-8656B) is fed to three systems: the RF system, a buncher system and a chopper system[7]. After the phase modulator the phase difference between two signals transmitted to the resonators is adjustable by the phase shifter. The amplitude of the signal is adjusted by the amplitude modulator. RF power is amplified by a three-stage amplifier system which consists of a 25 W solid-state wide-band amplifier and two grounded-cathode tetrode amplifiers(EIMAC 4CW800B and 4CW50,000E). The coupling coefficient of the final amplifier can be changed by adjusting the capacitance of a variable condenser provided in parallel with the coupling loop, without rotating the loop. The picked up signal of the dee voltage is transmitted to the amplitude modulator, the phase modulator and the phase discriminator through the dee voltage detector. The amplitude and phase of the dee voltage are automatically adjusted by comparing the picked up signal with the reference signal. The phase difference between the picked up signals from two resonators is detected by the phase discriminator, and transmitted to the phase shifter. The whole RF system is operated and monitored with a central computer[8].

Power test

Power tests have been carried out in the frequency range of 10.6 to 22.0 MHz. At the beginning of the tests, the dee voltage was not easily to be excited because multipactorings arose in the resonators. After repeated pulse excitation the multipactorings were reduced. The peak dee voltage of 60 kV was obtained at a frequency of 21.14 MHz. The output power of the final amplifier at the maximum dee voltage is around 22 kW. The dee voltage stability is better than $\pm 1\times 10^{-3}$ and the phase stability $\pm 0.5^\circ$ over the whole frequency range. The dee voltage ripple is less than 1×10^{-3} and the phase ripple 0.3° .

Conclusion

The $\lambda/4$ coaxial type resonator with the movable shorting plate was designed, manufactured and installed in the JAERI AVF cyclotron. Electrical characteristics of the resonator were measured by low-level tests. The resonant frequency range is 10.6~22.0 MHz. The measured Q-value and shunt impedance are consistent with the designed ones. Performance of the RF system has been examined in power tests. The maximum dee voltage of 60 kV at 21.14 MHz was obtained with less output power of the final amplifier than that for a movable-panel type resonator. Beam acceleration test has been now carried out without any serious trouble in the RF system.

References

1. K. Arakawa, *et al.*, "Construction and Present Status of the JAERI AVF Cyclotron", presented at this symposium.
2. R. Tanaka, *et al.*, Proc. of the 12th International Conference on Cyclotrons and their Applications, Berlin, 1989, pp.566-569.
3. W. Yokota, *et al.*, "Operation of ECR and Multi-cusp Ion Sources for the JAERI AVF Cyclotron", presented at this symposium.
4. W. Yokota, *et al.*, Proc. of the 7th Symposium on Accelerator Science and Technology, Osaka, 1989, pp.68-70.
5. T. Yamada, *et al.*, Proc. of the 11th International Conference on Cyclotrons and their Applications, Tokyo, 1986, pp.61-64.
6. Y. Nakamura, *et al.*, "Vacuum System of the JAERI AVF Cyclotron", presented at this symposium.
7. W. Yokota, *et al.*, Proc. of the 12th International Conference on Cyclotrons and their Applications, Berlin, 1989, pp.388-391.
8. S. Okumura, *et al.*, "Control System of the JAERI AVF Cyclotron", presented at this symposium.