A MODIFIED RF SYSTEM OF JAERI AVF CYCLOTRON

Y. Kumata, Y. Fukumoto
Sumitomo Heavy Industries, Ltd.
Niihama, Ehime 792 Japan,

M. Fukuda, K. Arakawa, 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

ABSTRACT

A $\lambda/4$ coaxial cavity with a movable short has been developed in the JAERI AVF cyclotron. The original model of this cyclotron had the movable panel type resonator, of which maximum voltage was not sufficient for accelerating 90 MeV protons. The maximum voltage of the modified coaxial cavity is 60 kV at 21.14 MHz. The resonant frequency range is 10.6 to 22.0 MHz, and the fine tunable frequency $\Delta f/f$ is 1.6 %. The voltage and phase stability is $\pm 1\times 10^{-3}$ and 0.5° respectively.

1. INTRODUCTION

The JAERI AVF cyclotron[1,2] (K-number=110) has been constructed for the purpose of extensive application of ion beams to R&D for radiation technology. 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 ion sources[3] in order to meet the requirement of producing light to heavy ions; one is a multicusp type ion source for generating protons, deuterons and helium ions, the other is an ECR type ion source mainly for heavy ions from proton to xenon. The ions with charge-to-mass ratio of 1 to 6.5 can be accelerated in a broad energy range: 5 to 90 MeV for protons, 5 to 53 MeV for deuterons, 10 to 108 MeV for $^4He^{2+}$, and 2.5 to $(110\times(Q/M)^2)$ MeV/u for heavy ions.

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 (Université Catholique de Louvain, Belgium), the IRE cyclotron (Institut National des Radioelements, Belgium) and NIRS-Chiba cyclotron (National Institute of Radiological Sciences, Japan). The latter three cyclotrons have a movable-panel type resonator with rf peak voltage of 35 kV at 21 MHz. A higher acceleration voltage of 60 kV was required for accelerating 90 MeV protons when the external ion sources were used. However, it is hard to get 60 kV by using the movable-panel type resonator owing to the power limit on the stem. The asymmetrical structure of the cavity causes the partial current concentration on the stem facing the movable panel, and then causes over-heated trouble on the stem and movable panel. The power consumption of the cavity was predicted to be 80 kW so as to operate at 60 kV and 21.14 MHz.

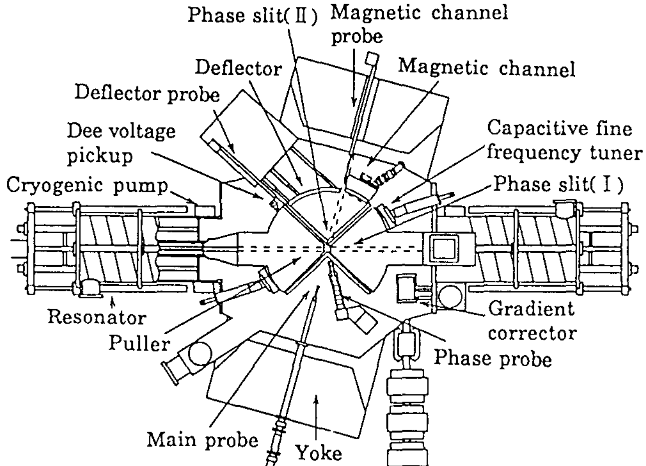

Fig. 1. Schematic drawing of the AVF cyclotron.

To avoid such a problem, the coaxial cavity with a movable short has been developed. The symmetrical structure of the cavity is more advantageous for the current density on the stem. The Q-value of the coaxial cavity, therefore, is higher than that of the movable-panel type cavity. Consequently, the power of 30 kW required for the amplifier is much less than before.

2. 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 86° are made of 10 mm thick oxygen free copper (OFC) so as to maintain a good thermal conductivity. Cooling water

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	$< \pm 1\times10^{-3}$
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

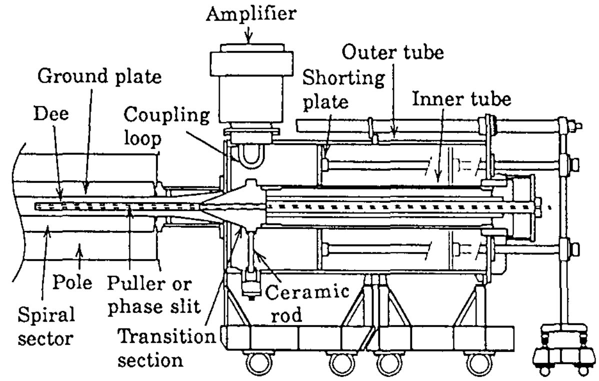

Fig. 2. Schematic view of the coaxial resonator with a movable shorting plate.

pipes are soldered on the inner surface of the dee. The gap between the dee and the ground plate is 42 mm, which is sufficient for the maximum voltage of 60 kV. The ground plate covering the trim coils is cooled indirectly.

The beam aperture inside of the dee is 40 mm. The acceleration gap in the center region is 17 mm and is increased radially up to 56 mm at r = 920 mm. The capacitive fine frequency tuner is located on the outer side of the dee. The tuner gap is adjustable from 8 mm to 50 mm automatically. The dee voltage is detected with a capacitive divider of which the ratio is 1/1000.

A puller extracting ions from inflector is inserted along the coaxial line of the cavity in contact with the inside surface of the dee. One of two phase slits is also inserted along the coaxial line of the other cavity and is movable radially.

A schematic view of the coaxial cavity is shown in Fig. 2. The dee is connected through the transition section to the inner coaxial line. The one end of the inner line is supported with a ceramic rod and the other end is supported with the end plate of the cavity. The outer diameter of the inner coaxial line is 300 mm and the inner diameter of the outer coaxial line is 1000 mm. The length of the cavity is approximately 2000 mm. They are made of OFC. The inner line is composed of three tubes so as to keep a go-and-return path of the cooling water and the space for the puller or the phase slit. The outer cavity is cooled by copper pipes which are wound around it. The outer cavity can be separated into front and rear parts when the maintenance of the movable short is necessary. The stroke of the movable short is 1350 mm so as to cover the required frequency range from 10.6 MHz to 22.0 MHz. The shorting plate has many contact fingers made of the Be-Cu. They are pressed to the inner and outer coaxial line with the pneumatic bellows. The contact piece on the finger is made of silver containing 5 % graphite. The final amplifier is directly mounted on the front part of the outer cavity and is coupled with the resonator by a loop coupling. The loop, made of 40 mm diameter copper pipe, is cooled by water. A couple of the cryogenic pumps (4000 l/s each) are mounted on the bottom of the cavity. An rf shield consisting of copper pipes was attached on the each pumping port to shield the leakage of rf power from the cavity to the pump.

3. CHARACTERISTICS OF THE RESONATOR

The electrical characteristics of the resonator have been measured by using a network analyzer (HP-8753A). A low level rf power was fed through a small capacitor facing to the final tetrode so as to avoid perturbation, and dee voltage was detected with capacitive divider. The resonant frequency is shown in Fig. 3 as a function of the movable short position. The frequency range adjusted by fine tuner is shown in Fig. 4 as a function of the tuner gap. The relative frequency range is 1.6 % for 10.585 MHz and 22.237 MHz.

The measured Q-value and the shunt impedance are shown in Fig. 5 and Fig. 6 as a function of resonant frequency. The shunt impedance was measured by a perturbation method using a small capacitor of which the capacitance was measured exactly. 75 % of the calculated values are shown with solid lines in Figs. 5 and 6, and are well consistent with measured values. The one-dimensional transmission line model is used for the calculation. For the comparison, the measured values of the movable panel type cavity are shown in dashed lines in Figs. 5 and 6. The shunt impedance in higher frequency region has been much improved by approximately 4 times.

4. AMPLIFIER

A schematic diagram of the amplifier is shown in Fig. 7. The amplifier is composed of one solid-state amplifier and two stage tetrodes (EIMAC 4CW800B and 4CW50,000E). They are used as grounded-cathode configuration to raise higher power gain. The all pass net-

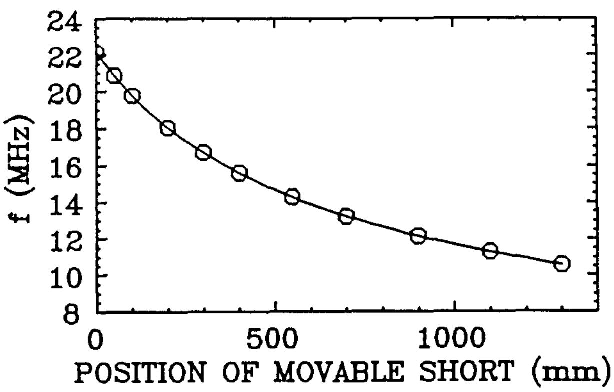

Fig. 3. Resonant frequencies of the resonator as a function of position of the movable shorting plate.

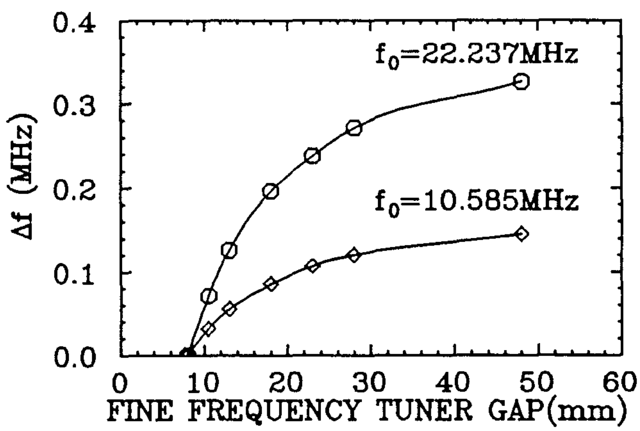

Fig. 4. Adjustable frequency by the capacitive tuner at 22.237 MHz and 10.585 MHz. The full relative frequency change is 1.6 %.

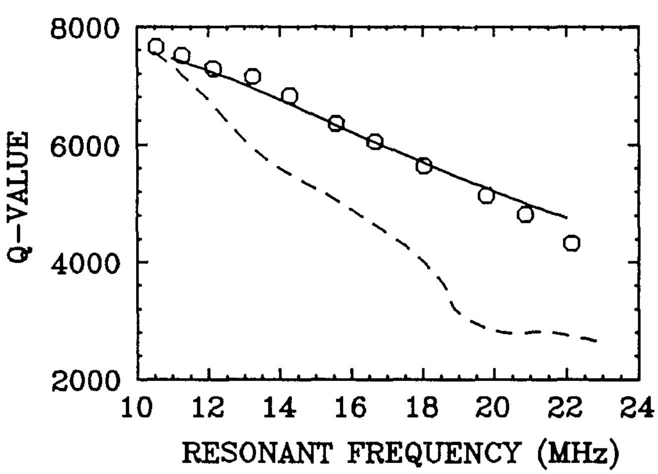

Fig. 5. Frequency dependence of Q-value. The solid line shows 75 % of the calculated value based on one-dimensional transmission line approximation. The dashed line shows the measured value of the movable panel type cavity.

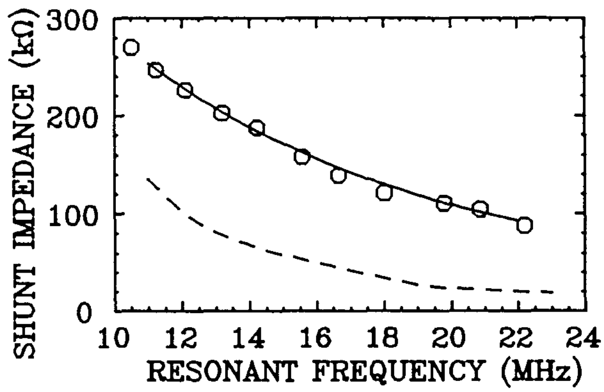

Fig. 6. Frequency dependence of shunt impedance. The solid line shows 75 % of the calculated value based on one-dimensional transmission line approximation. The dashed line shows the measured value of the movable panel type cavity.

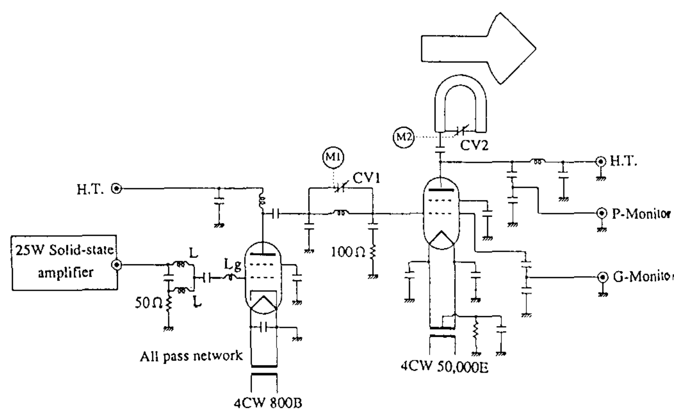

Fig. 7. Schematic diagram of the amplifier system.

work[4] is adopted for the input matching circuit of the pre-amplifier. This circuit has the advantage that no adjustment is required in the frequency range from 10 to 22 MHz. The final tetrode is coupled directly to the cavity through a loop coupling. A variable vacuum capacitor connected parallel to the loop is used for the adjustment of the coupling impedance.

5. LOW LEVEL CONTROL SYSTEM

The block diagram of the low level control system is shown in Fig. 8. The rf signal from a master oscillator (HP-8656B) is divided into three ways: the main rf system, a buncher system and a chopper system. The phase modulator stabilizes the absolute phase between the master oscillator and the No.1 dee on which the puller is mounted. The following phase shifter controls the relative phase between the two dees. The amplitude of the rf signal was controlled with the amplitude modulator.

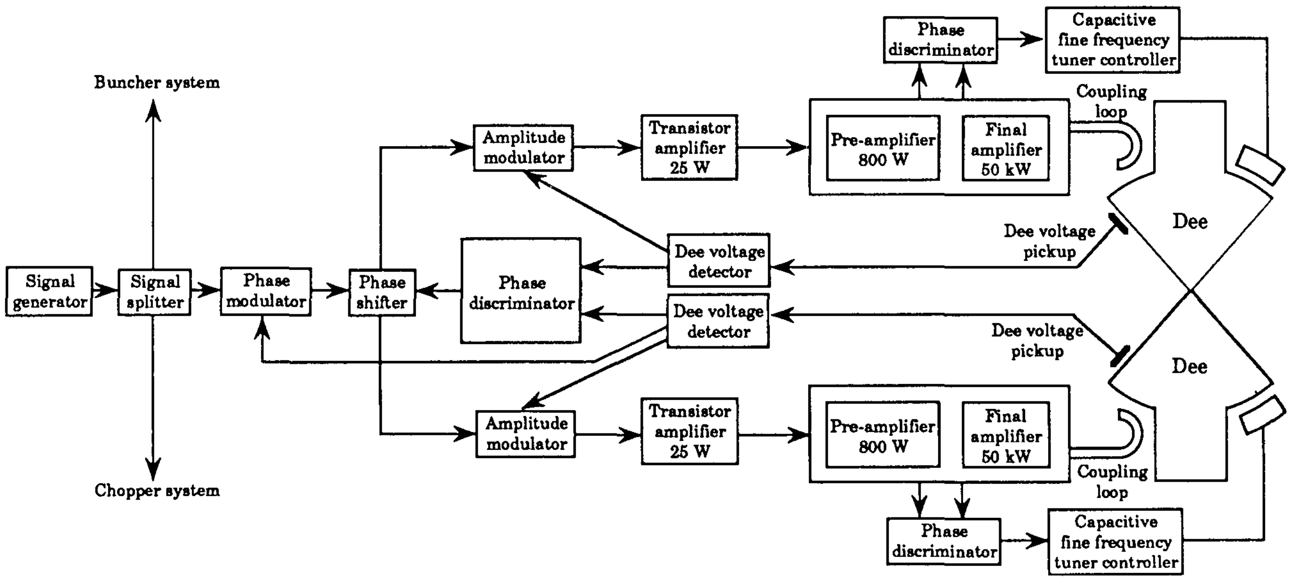

Fig. 8. Block diagram of the rf control system.

The rf signal is amplified with three-stage amplifier system: a 25 W solid-state amplifier and two tetrodes. The dee voltage is detected with capacitive pick-up method and fed to the dee voltage detector. The signal is divided and fed back to the phase discriminator, the amplitude modulator and the phase modulator. The capacitive fine tuner is controlled by the phase discriminator detecting phase difference between the grid and plate rf voltages of the final tetrode.

The operation sequence of the rf system is controlled automatically by a micro processor named "Universal Device Controller" (UDC).[5] The UDC is communicated with a host computer by optical fiber.

6. POWER TEST AND OPERATION

The power test has been carried out successfully in the frequency range of 10.6 MHz to 22.0 MHz. The required voltage in every frequency point has been achieved as shown in Fig. 9. The maximum voltage of 60 kV has been achieved at 21.14 MHz with a low power consumption of 22 kW measured by calorimetric method. The voltage and phase stability are better than $\pm 1\times 10^{-3}$ and $\pm 0.5°$ respectively over the whole frequency range. The dee voltage ripple is less than 1×10^{-3} and the phase ripple 0.3°. In the early days of operation, it took some minutes to overcome multipactorings in pulse mode operation. But in these days, it is easy to start up the rf system. The operation time so far is approximately 2000 hours and no serious trouble has been suffered.

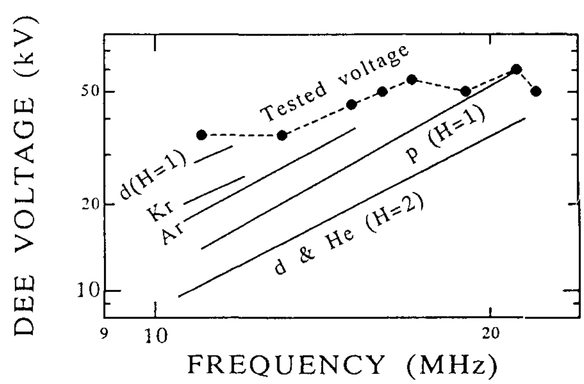

Fig. 9. The required dee voltage and tested voltage as a function of frequency.

7. REFERENCES

1) Tanaka, R. et al., "JAERI AVF cyclotron for research of advanced radiation technology," presented at the Conference on Cyclotrons and Their Applications, Berlin, Germany, May 8-12, 1989.
2) Arakawa, K. et al., "Construction and first year's operation of the JAERI AVF cyclotron," presented at this conference.
3) Yokota, W. et al., "Operation of ion sources and beam transport to JAERI AVF cyclotron," presented at this conference.
4) Mosko, S.W., Raylander, J.D., Shulze, G.K., "ORIC rf system preparation for HHIRF", IEEE Trans. Nucl. Sci., **NS-24**, pp. 1786-1788, June 1977.
5) Okumura, S. et al., "Control system for JAERI AVF cyclotron," presented at this conference.