THE RF SYSTEM FOR THE RCNP RING CYCLOTRON

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ABSTRACT

The RF system for the RCNP ring cyclotron is described. The RF system consists of three single gap acceleration cavities and a single gap flat-topping cavity. One of the acceleration cavities and the flat-topping cavity have been delivered. 250 kW RF power amplifiers for the acceleration cavities were made and have been tested by using a dummy load. Phase stabilizing circuits are also investigated.

INTRODUCTION

The cyclotron cascade project of RCNP approved in 1986. General features of the project is described elsewhere[1,2]. Fig. 1 shows relation between orbital frequencies and acceleration frequencies in the present AVF cyclotron and ring cyclotron for various ions and energies. The harmonic numbers of acceleration are also shown. Frequency range of the acceleration system is 30~52 MHz and harmonic numbers of acceleration is 6, 10, 12 and 18. Third harmonic of the acceleration frequency is used in flat-topping system. Characteristics of the acceleration system and the flat-topping system are summarized in Tables 1 and 2. Three acceleration cavities and one flat-topping cavity are installed in the ring cyclotron[3]. These resonators are variable frequency single gap cavities. A new type variable frequency resonator was developed for the acceleration cavity. Excellent phase stability is required to get high energy quality beam with flat-topping. Preliminary study of a phase regulation system has been made. RF power amplifiers for the acceleration cavities, one of the three acceleration cavities and the flat-topping cavity were delivered. Measurements of electrical characteristics of the amplifiers and cavities are under way.

ACCELERATION CAVITY

The cavity is variable frequency single gap resonator. A 1/5 scale model of the cavity was made to determine final mechanical and RF characteristics. Fig. 2 shows schematic drawing of the acceleration cavity. The resonant frequency is varied by rotating a pair of tuning plates. The plates are electrically connected to a wall of the cavity through current-carrying hinges. Fig. 3 shows mechanical configuration of the hinges. Maximum current density at the copper plate of the hinge is 20 A/cm. The copper plate proved to bear more than 10^5 cycles of 90° bending test at room temperature. The fine tuning is done by changing the inductance with two cylindrical trimmers.

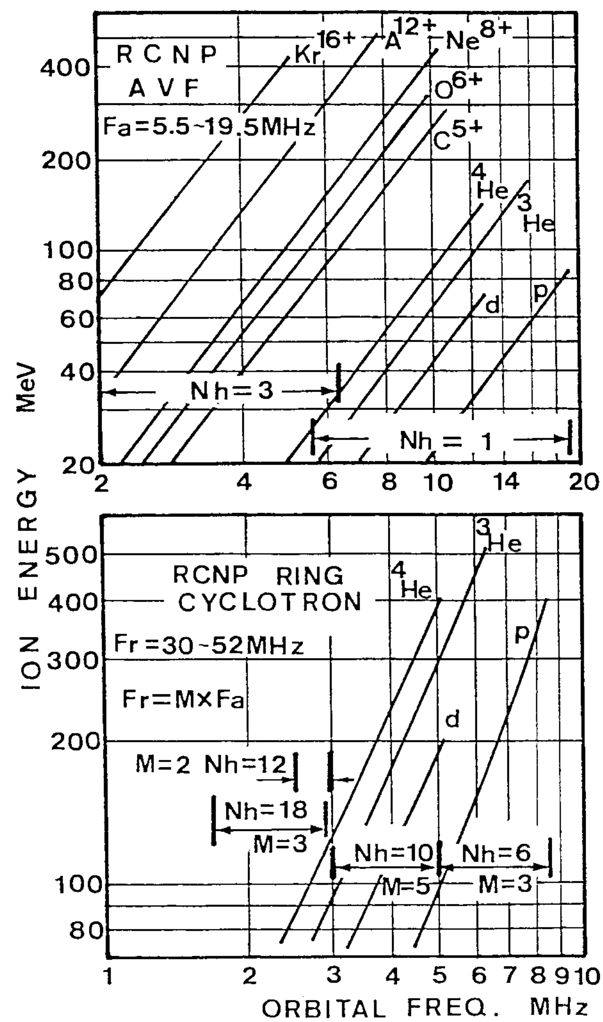

*Fig.*1 Orbital frequencies, acceleration frequencies and harmonic numbers of acceleration in the present AVF cyclotron and the Ring Cyclotron. M is ratio of the RF frequency of the Ring cyclotron to the AVF cyclotron.

Table 1
Characteristics of the acceleration system.

RF frequency	30 ～ 52 MHz
Harmonic Number	6, 10, 12, 18
Number of cavities	3
RF peak voltage	500kV
RF voltage stability	10^{-4}
RF phase excursion	± 0.1°
RF power	～250kW/cavity
RF power amp. (1st stage)	TR wideband 500W
RF power amp. (2nd stage)	RS2012CJ grounded cathode
RF power amp. (final)	RS2042SK grounded grid 250kW
Resonator	single gap
Power feeder	inductive coupling
Beam aperture	30mm x 2310mm
Acceleration gap	200 ～ 300mm
Mean injection radius	2000mm
Mean extraction radius	4000mm

Table 2
Characteristics of the flat-topping system.

RF frequency	90 ～ 155 MHz
Number of cavities	1
RF peak voltage	170kV
RF voltage stability	10^{-3}
RF phase excursion	± 0.3°
RF power	～30kW
Resonator	single gap
Power feeder	inductive coupling
Beam aperture	30mm x 2130mm
Acceleration gap	50mm

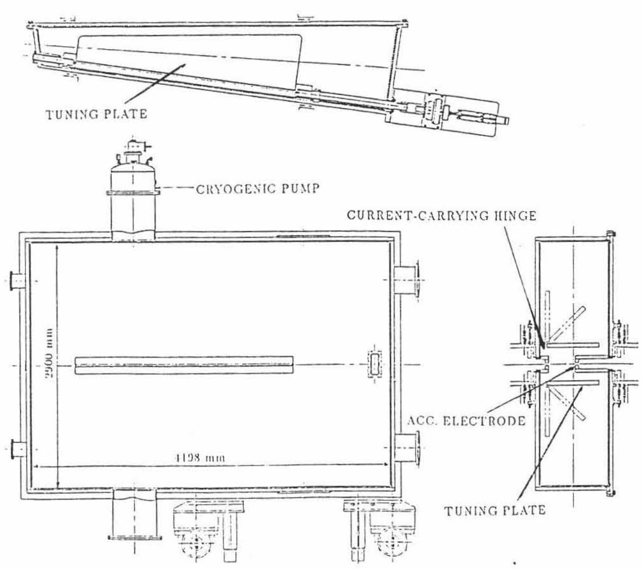

*Fig.*2 Schematic drawing of the acceleration cavity.

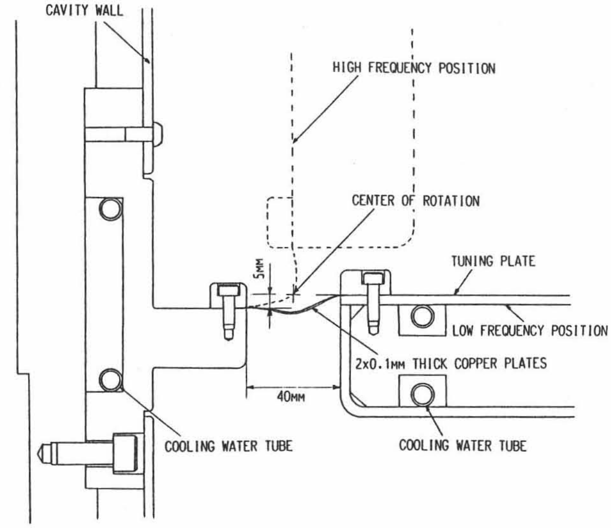

*Fig.*3 Current carrying hinge.

Cooling water of the plates is fed through centering shafts. The walls of the cavity are made of stainless steel with water cooled copper lining. Acceleration electrodes are made of copper. The copper skin of the capacitive tuning plates are sustained by aluminum frameworks. The cavity is evacuated by 20 inch cryopump. The cavities are able to be withdrawn easily along rails for the maintenance. The interface surfaces between magnet chambers and the cavities are sealed by pneumatic expansion seals. The side walls of the cavity is not strong to support atmospheric pressure. The support for the atmospheric pressure is provided by the neighbouring magnet chambers. Quick disconnectable clumps are equipped to unite the cavity with the magnet chambers.

Fig. 4 shows distributions of acceleration voltage along the acceleration gap measured with the model cavity. The voltages are normalized to the maximum voltage. Radially increasing voltage distributions are obtained. Voltage distributions show a little frequency dependence.

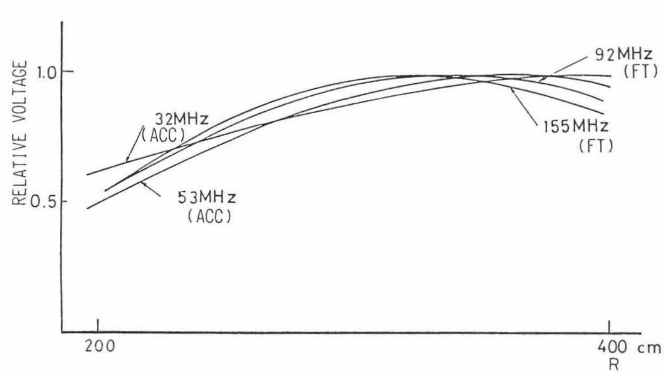

*Fig.*4 Distributions of acceleration voltage along the acceleration gap measured with the model cavities.

FLAT-TOPPING CAVITY

A single gap resonator is also used for the flat-topping cavity. Fig. 5 is schematic drawing of the flat-topping cavity. The mechanical structure of the cavity wall is similar to that of the acceleration cavity. Resonant frequency is changed by sliding the upper and lower walls of the cavity. Each sliding wall is supported by two rods which have piping for cooling water and pneumatic pressure. The sliding walls have silver contacts. The contacts are pressed to the side walls by pneumatic pressure. The cavity has a pair of lips at acceleration gap. The flat-topping cavity is designed to get similar voltage distributions to those of the acceleration cavity. Fig. 4 shows distribution of flat-topping voltage. The frequency range of the flat-topping cavity is higher than the cutoff frequency of RF reakage through the beam aperture. The reakage signal might disturb beam phase probes. A pair of pick-up electrode is prepared to detect the vertical component of the field. The field will be canceled by correcting the position of the sliding walls.

A preliminary measurements of electrical characteristics of the flat-topping cavity have been done. The measured Q values of the cavity are $1.7 \sim 2 \times 10^4$.

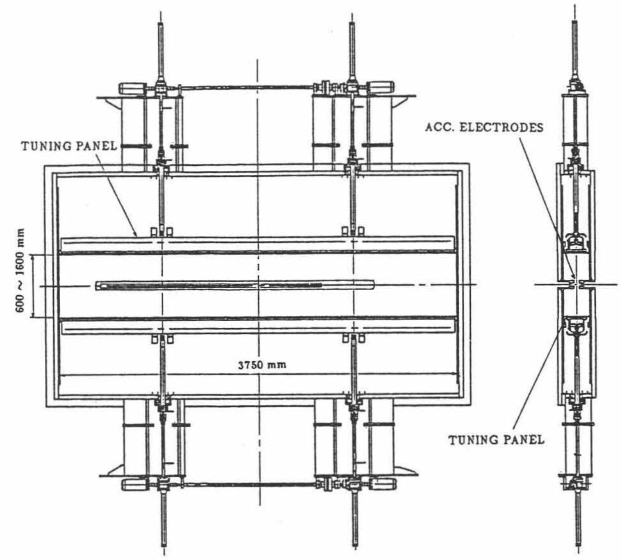

*Fig.*5 Schematical drawing of the flat-topping cavity.

SYNCHRONIZED OPERATION SYSTEM

Fig. 6 shows a block diagram of the RF system. Acceleration frequency of the injector cyclotron, generated by a frequency synthesizer, is used as clock signal of the ring cyclotron. The clock signal is converted to the acceleration frequency of the ring cyclotron by a frequency multiplier. The signal generator and divider block generates acceleration frequency, flat-topping frequncy, buncher frequency, local frequencies and intermediate frequency. Intermediate frequency is used in phase control systems and auto tuning servo systems.

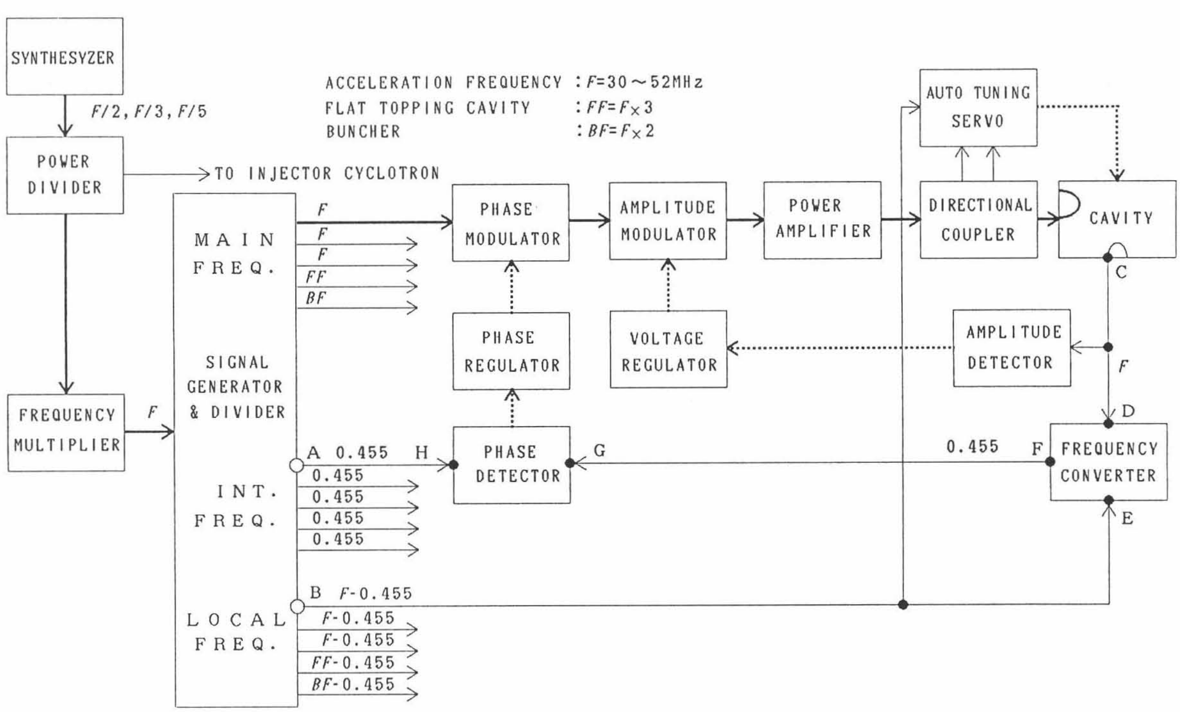

*Fig.*6 Block diagram of the RF system.

Acceleration voltage is stabilized comparing rectified voltage of picked-up signal with reference voltage.

PHASE REGULATOR SYSTEM

Phase stability between the cavities should be less than $\pm 0.1°$ to accelerate 400 MeV proton with good energy resolution ($< 10^{-4}$). A long term phase excursion of RF power amplifier system was measured on present AVF cyclotron. The result shows that the phase excursion is less than $\pm 1°$ without phase stabilizing loop. Main source of phase drift comes from wideband amplifier.

The thermal effect of coaxial cable on phase excursion is important. Following methods are adopted to reduce the thermal effeft of coaxial cable on phase excurtion of the RF signals.

a) arranging the apparatuses of the RF system so as to be able to use short RF cables.

b) lay RF cables in ambient temperature as same as possible.

c) application of a low intermediate frequency by means of heterodyne method.

d) selection of coaxial cable of which thermal coefficient of propagation velocity is low.

e) adjusting the cable length to cancel the propagation time.

If high frequency signals propagate through long line, thermal effect on the propagation time is not negligible to get phase stability better than $\pm 0.1°$. Thermal coefficients of propagation time were measured for various coaxial cables. The results for polyethylene cable and foaming polystyrol cable are shown in Fig. 7. The thermal coefficient of propagation time of polyethylene cable and foaming polystyrol cable are $-2 \times 10^{-5} \sim 2 \times 10^{-4}$ and $-2 \times 10^{-5} \sim -1 \times 10^{-5}$, respectively for the temperature range around $20 \sim 40°C$.

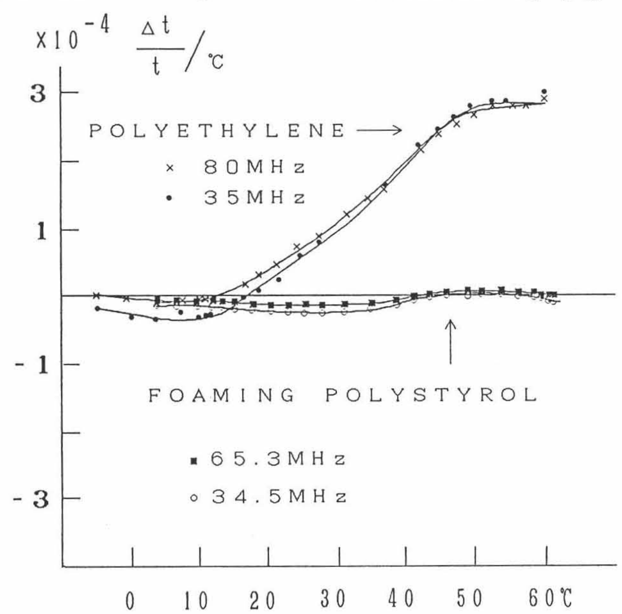

Fig.7 Thermal coefficient of propagation time of coaxial cables.

A block diagram of the phase stabilizing loop is also shown in Fig. 6. A and B are phase reference point and the phase at C should be stabilized. The cable lengths between CD, BE, AH and FG are taken into consideration to cancel the propagation time effect. Phase sift Φ generated by these cables is as follows.

$$\Phi \propto \Omega(CD - BE) + \omega(FG + BE - AH) \quad (1)$$

where $\Omega = 2\pi F$ and $\omega = 2\pi \times 0.455$.
To cancel the propagation time effect, the following relations are needed between cable length CD, BE, AH and FG.

$$CD = BE \quad (2)$$
$$AH = FG + BE \quad (3)$$

CD and BE relate to high variable frequency (F=30 $\sim$ 52 MHz) signal , the equation (2) is more important than equation (3). In contrast to equation (2), equation (3) relates to low (0.445 MHz) constant frequency signal . Design study of phase control system is in progress.

SUMMARY

Variable frequency single gap acceleration cavity was developed. One of the acceleration cavities, flat-top cavity and RF power amplifiers for the acceleration cavities were delivered. In the RCNP ring cyclotron system, flat-topping system is used to accelerate high quality beam. With this system excellent phase stability is needed. For required phase stability, effects of coaxial cables on propagation time is not negligible. Methods to eliminate these effect are investigated.

References

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