RF SYSTEM OF RCNP RING CYCLOTRON PROJECT

T. Saito, H. Tamura, A. Shimizu and I. Miura
Research Center for Nuclear Physics, Osaka University
Mihogaoka, Ibaraki, Osaka 567, Japan

Summary

The RF system for the RCNP six-separated spiral sector cyclotron is studied. The RF system consists of three acceleration cavities and one flat-topping cavity. An acceleration cavity and a flat-topping cavity are investigated on models.

Introduction

The cyclotron cascade project of RCNP was approved in 1986. The construction of the facility will start in 1987. General features of the project is described elsewhere.[1] Main facility of the project is K=400 six-separated spiral sector cyclotron (SSC). Maximum energy of the SSC is 400 MeV for protons and alpha particles. The plan view of the cyclotron is shown in Fig. 1. Three acceleration cavities and one flat-toppig cavity are installed between sector magnets. Dee in-valley 1/2λ type cavities or single gap cavities will be used as the acceleration cavities. The present AVF cyclotron with 180°-single dee is to be used as the injector for the SSC. Frequency range and harmonic numbers of the acceleration in the SSC are chosen to fit the present AVF cyclotron.

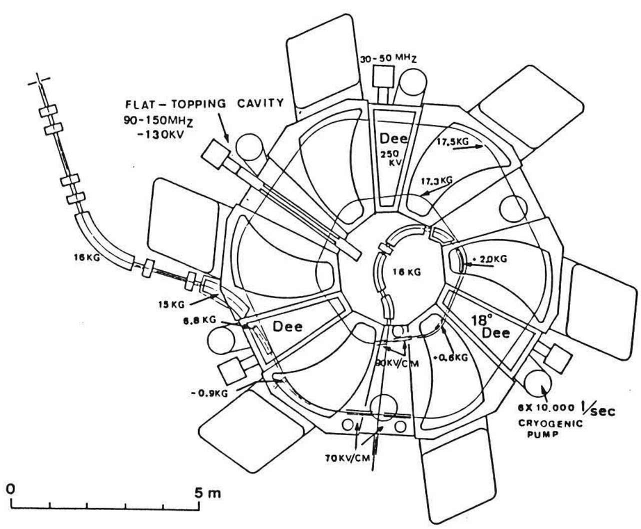

Fig.1. Plan view of the separated sector cyclotron.

Outline of RF system

The frequency range of the acceleration system for the SSC is 30 - 50 MHz. Acceleration harmonic numbers are 6 and 10. In the present AVF cyclotron, frequency range is 5.5 - 19.5 MHz and fundamental acceleration mode is used for protons and alpha particles. As the injection radius of the SSC is twice the extraction radius of the present AVF cyclotron, orbit frequency of the injector cyclotron is twice as much that of the SSC. Orbit frequencies, acceleration frequencies and harmonic numbers of acceleration in the two cyclotrons for various ions and energies are shown in Fig. 2. In the initial phase of the project, different acceleration frequencies will be used for the two cyclotrons.

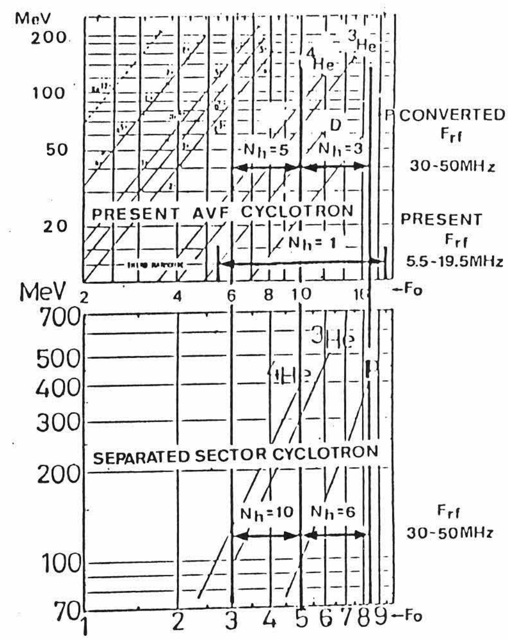

Fig.2. Orbit frequencies (F_0), acceleration frequencies (F_{rf}) and harmonic number of acceleration (N_h) in the present AVF cyclotron and separated sector cyclotron.

It is desirable to use same acceleration frequency for the injector cyclotron and the SSC. Converting the frequency range of the 180°-single dee RF system of the injector cyclotron to 30 - 50 MHz in future, the same acceleration frequencies can be used. There is another choice of frequency range (22.2 - 33.3 MHz) and acceleration harmonic numbers for the SSC (4 and 6). To accelerate protons by 4th harmonic mode in the SSC, the injector cyclotron should accelerate by 2nd harmonic mode with two dee acceleration system. For this scheme a completely reconstruction on the injector cyclotron including exchange of an extraction system is necessary. Then the acceleration frequency range 22.2 - 33.3 MHz was not chosen.

Characteristics of the acceleration system and the flat-topping system are summarized in Tables 1 and 2, respectively. In phase and three phase RF operation of these three acceleration cavities need for harmonic number of 6 and 10, respectively. The phase errors between these three acceleration cavities and one flat-topping cavity in the SSC should be less than 0.1° to get energy resolution better than 10^{-4} for accelerated beam.[2] Energy gain 1.5 MeV per turn need for 400 MeV proton acceleration to get turn separation of 5mm at the extraction radius. Radially flat distribution of the acceleration voltage is desirable for this SSC. The energy spread of the extracted beam from the injector depends on that of injected beam and proportional to the ratio of the acceleration voltage at extraction radius to injection radius.[2]

Table 1
Characteristics of the acceleration system.

RF frequency	30 ~ 50 MHz
Harmonic Number	6,10
Number of cavities	3
Energy gain/turn/charge	1.5 MeV
RF voltage stability	10^{-4}
RF phase excursion	±0.1°
FR power	~250kW/cavity
Mean injection radius	2000mm
Mean extraction radius	4040mm
Beam aperture	30mm

Table 2
Characteristics of the flat-topping system.

RF frequency	90 ~ 150 MHz
Number of cavities	1
RF peak voltage	150kV
RF voltage stability	10^{-4}
RF phase excursion	±0.1°
FR power	~25kW
Resonator	single gap
Beam aperture	30mm

The energy width of the injection beam will be limited by a beam energy analyzer between the injector cyclotron and the SSC. A conventional flat-topping method is used for the SSC. The flat-topping voltage is about 10 % of the total acceleration voltage. The flat-topping frequency is 3rd harmonic of the acceleration frequency. With this flat-topping increased phase acceptance and precise energy resolution and clear turn separation can be realized. The block diagram of the RF system is shown in Fig.3 Two frequency synthesizers which are phase locked to a common frequency standard are used as master oscillators for the injector cyclotron and the SSC. The acceleration voltage of each cavity will be adjusted independently to suppress radial oscillation of the beam.[2]

As the gaps of the magnets are 6 cm, a dee in-valley structure or single gap type cavity should be used. The radial length of the acceleration gap is longer than 2 m corresponding to the difference of extraction radius from injection radius. The height of magnets are about 5m. The cavity should be easily extracted radially for maintenance. Then allowed azimuthal spaces are at most 18°. The height of the cavities including driving systems of tuning mechanisms should not be much higher than those of the sector magnets for maintainability and cost reduction. To satisfy these conditions 1/2λ type cavities and single gap cavity were investigated by models.

1/2λ type acceleration cavity

A 1/2λ type cavity has two vertical stems with sliding shorts and 17° delta shaped dee. Two types of stems were tested on 1/5 scale models. One has a delta-shaped cross section and the other has a coaxial one.

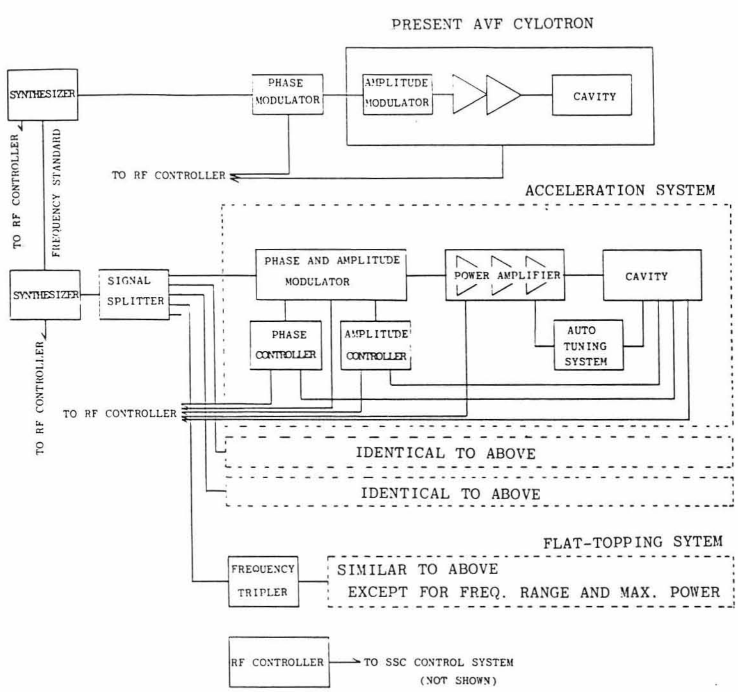

Fig.3. Block diagram of the RF system.

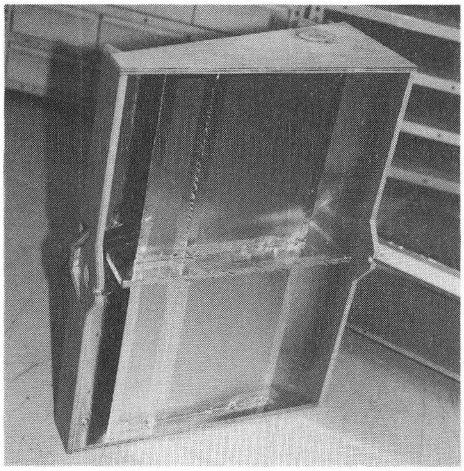

Fig.4. 1/5 scale model cavity with delta shaped stems.

Delta shaped stem cavity

A photograph of 1/5 scale model cavity with delta shaped stems is shown in Fig.4. The radial voltage distribution along the dee gap is convex-shape. The radial dependence of the voltage distribution is not strong. The height of the cavity which resonates 30 MHz is 5m. The power loss of the cavity is estimated to be 300 kW at 250 kV_{peak} (50 MHz) excitation. These demerits; the cavity height and the large power loss, come from low stem impedance. The impedance of the delta-shaped stem is limited at most 20Ω by the spatial restriction between sector magnets. However these characteristics of this cavity is acceptable for the acceleration system of the SSC.

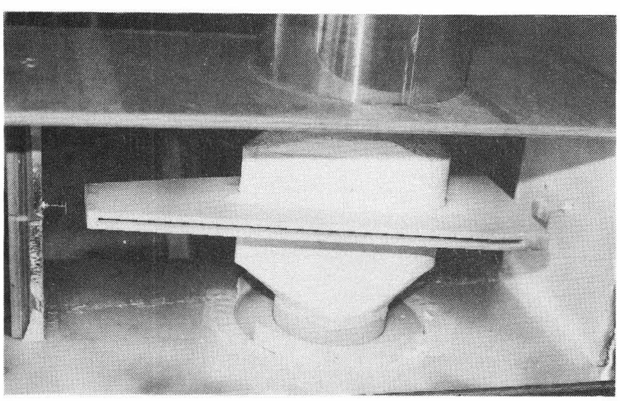

Fig.5. 1/5 scale model cavity with coaxial stems.

Coaxial stem cavity

A 1/2λ type cavity with coaxial stems are studied. Fig.5 shows the photograph of the 1/5 model cavity. The diameters of inner and outer conductors are 140 mm and 240 mm, respectively. These diameters were decided considering spatial restriction and stem impedance. The diameter of the outer conductor is limited by the space of the valley section. To reduce power loss and height of the cavity, the stem impedance is decided to be about 30Ω. According to high stem impedance, the height of the cavity is less than 3m, and maximum power loss is estimated to be about 200kW. Although this cavity has following disadvantages. Since the length of the dee electrode is nearly equal to a half-wave length of the maximum RF frequency (50 MHz) and the wave travels also radially, it is difficult to make a cavity to resonate up to 50 MHz. An effect of the traveling wave along radial direction the cavity voltage has strong radial dependence. This radial voltage distribution also shows strong frequency dependence. Therefore, this type of cavity seems to be impractical for this SSC.

Single gap acceleration cavity

A single gap type cavity is also studied to reduce RF power loss and cavity size. A fairly well voltage distribution can be obtained with proper choice of radial length of the cavity and shape of acceleration electrodes in the given geometrical condition. Single gap cavity has high acceleration efficiency for any harmonic mode acceleration. The transit time effect is not severe on 10th harmonic acceleration, even if wide acceleration gap was needed to withstand a voltage twice as high as that of 1/2λ type cavity. Various studies are now in progress on 1/10 scale model for this cavity.

Flat-topping cavity

A single gap cavity is used for the flat-topping cavity. A 1/5 scale model of the single gap flat-topping cavity was made to investigate RF characteristics. Fig. 6 shows the model cavity. The cavity has a pair of lips at acceleration gap. The acceleration gap is 50 mm. RF power is fed to the cavity through an inductive power feeder. Resonance frequency is varied by a pair of sliding tuner plates as shown in Fig. 6. The radial length of the beam aperture is about 2m. The cutoff frequency of the 2m aperture is 75 MHz for up-down mode oscillation. Up-down symmetry is important to reduce unwanted leakage of RF power through the beam aperture. The radiation from the aperture may perturb beam phase probes.

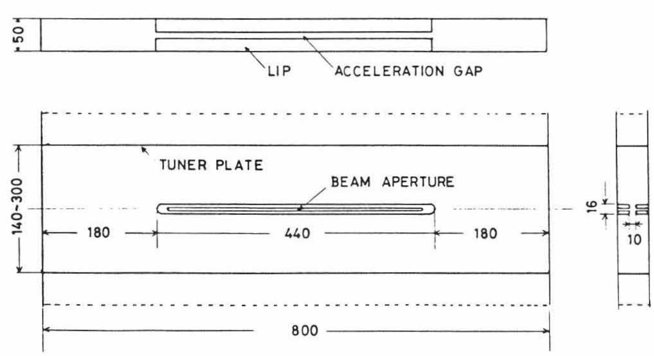

Fig.6. 1/5 scale model of flat-toppig cavity.

Resonance frequencies of the cavity was measured up to 1.4 GHz vs. position of the tuner plates. Fig. 7 shows the result. Various modes of resonance were observed. H101 mode resonance is used for flat-topping. The measured voltage distribution is shown in Fig. 8 Voltage distribution along the acceleration electrode shows a little frequency dependence.

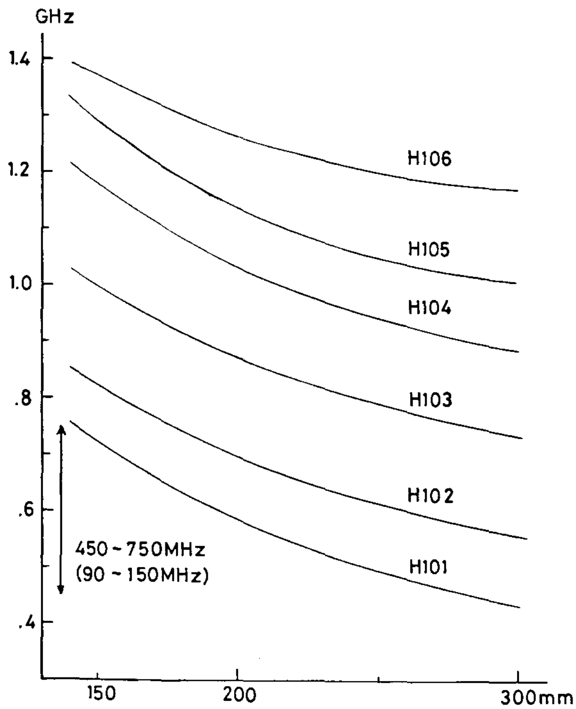

Fig.7. Resonance frequencies of the model cavity.

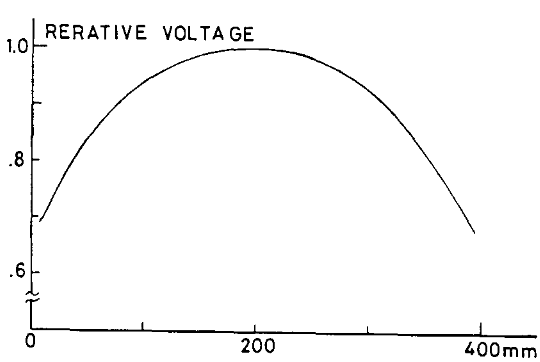

Fig.8. Radial voltage distribution of the flat-topping cavity at 752 MHz.

References

1. T. Miura et al., "Proposal for Cyclotron Cascade Project", in these proceedings.
2. T. Yamazaki et al., "Beam Quality Study in RCNP Six-sector Ring Cyclotron", in these proceedings.