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# RF SYSTEM OF RCNP RING CYCLOTRON PROJECT

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## 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

General features of the ring cyclotron project is described elsewhere.[1] Main facility of the project is K=400 six-separated spiral sector cyclotron (ring cyclotron). Maximum energy of the ring cyclotron 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-topping cavity are installed between sector magnets. Single gap cavities are used as the acceleration cavities. The present AVF cyclotron with 180°-single dee is to be used as the injector for the ring cyclotron. Frequency range and harmonic numbers of the acceleration in the ring cyclotron are chosen to fit the present AVF cyclotron.

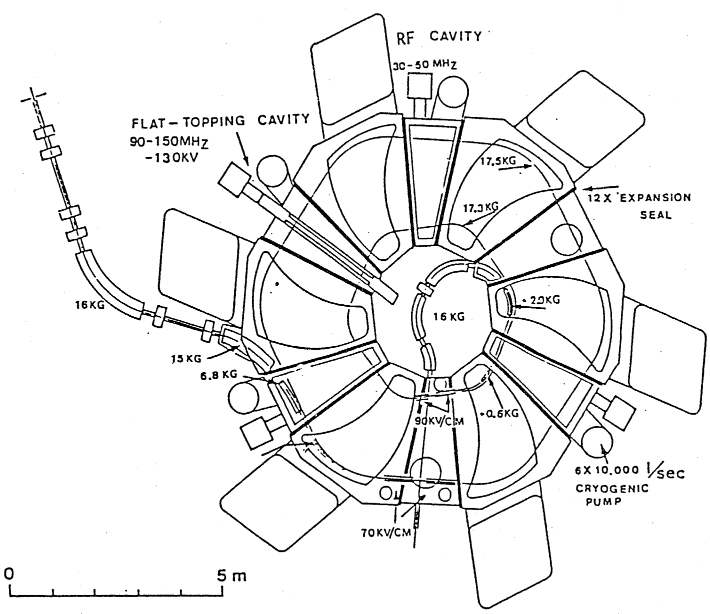


**Fig. 1 Plan view of the ring cyclotron**

## Outline of RF system

The frequency range of the acceleration system for the ring cyclotron is 30 - 52 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 ring cyclotron is twice the extraction radius of the present AVF cyclotron, orbit frequency of the injector cyclotron is twice as much that of the ring cyclotron. In the initial phase of the project, different acceleration frequencies will be used for the two cyclotrons.

It is desirable to use same acceleration frequency for the injector cyclotron and the ring cyclotron. Converting the frequency range of the 180°-single dee RF system of the injector cyclotron to 30 - 52 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 ring cyclotron (4 and 6). To accelerate protons by 4th harmonic mode in the ring cyclotron, 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 ring cyclotron should be less than 0.1° to get energy resolution better than $10^{-4}$ for accelerated beam. Energy gain of 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 ring cyclotron. 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.

Table 1
Characteristics of the acceleration system.

| | |
|---|---|
| RF frequency | 30 ~ 52 MHz |
| Harmonic Number | 6,10 |
| Number of cavities | 3 |
| RF peak voltage | 500kV |
| RF voltage stability | $10^{-4}$ |
| RF phase excursion | ±0.1° |
| RF power | ~250kW/cavity |
| Resonator | single gap |
| Beam aperture | 30mm |
| Acceleration gap | 200 ~ 300mm |
| Mean injection radius | 2000mm |
| Mean extraction radius | 4040mm |

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 | ±0.1° |
| RF power | ~30kW |
| Resonator | single gap |
| Beam aperture | 30mm |
| Acceleration gap | 50mm |

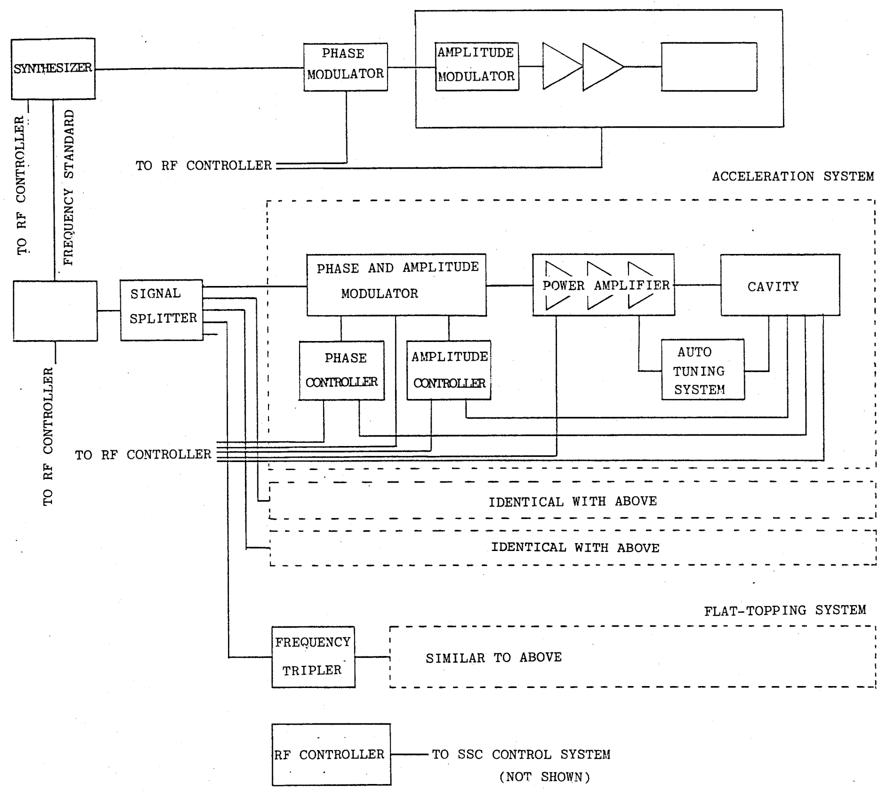


Fig.2. Block diagram of the RF system.

The energy width of the injection beam will be limited by a beam energy analyzer between the injector cyclotron and the ring cyclotron. A conventional flat-topping method is used for the ring cyclotron. 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.2 Two frequency synthesizers which are phase locked to a common frequency standard are used as master oscillators for the injector cyclotron and the ring cyclotron. 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 available 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 single gap cavity was chosen and detailed investigations were done on models.

## Single gap acceleration cavity

A single gap type cavity is studied to reduce RF power loss and cavity size. 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. New method to vary the resonance frequency has been developed on 1/5 scale model.

The 1/5 scale model is shown in Fig. 3. The cavity has a pair of tuner plates to vary the resonance frequency. The resonance frequency is varied by rotation of the tuner plates. Resonance frequency vs. angle of the tuner plates are shown in Fig. 4. $H_{101}$ mode resonance is used for acceleration. RF power is fed to the cavity through an inductive power feeder.

The measured voltage distributions along the acceleration electrode are shown in Fig. 5. The voltage distributions are radially increasing and show convex shape.

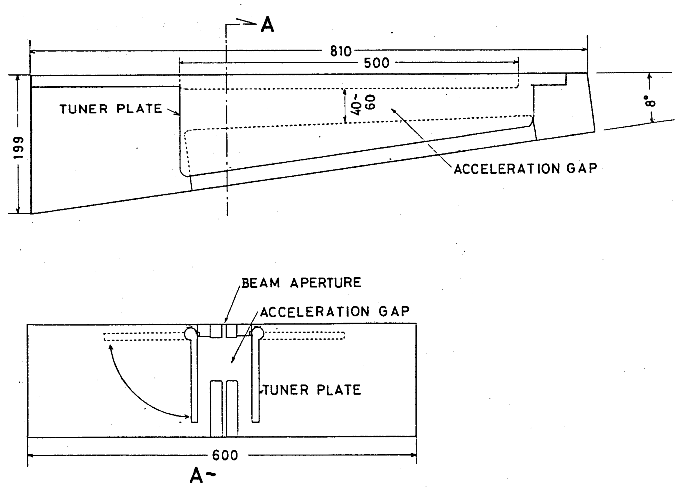


Fig.3. 1/5 scale model of single gap acceleration cavity.

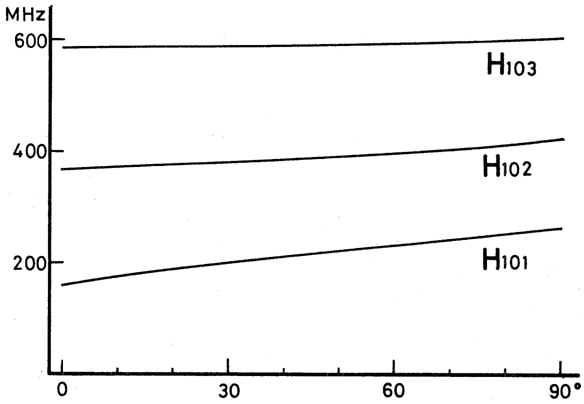


Fig.4. Resonance frequencies vs. angle of tuner plates.

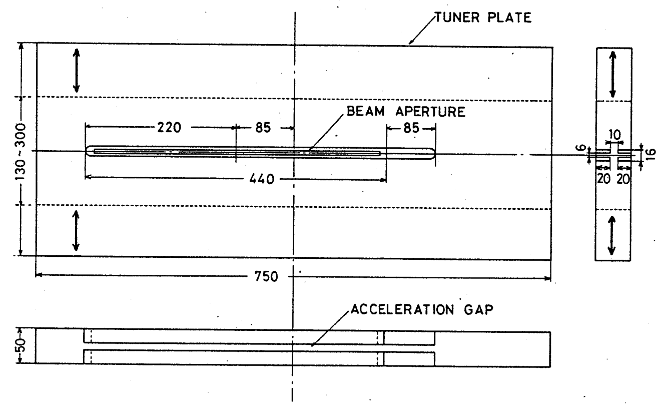


Fig.6. 1/5 scale model of single gap flat-topping cavity.

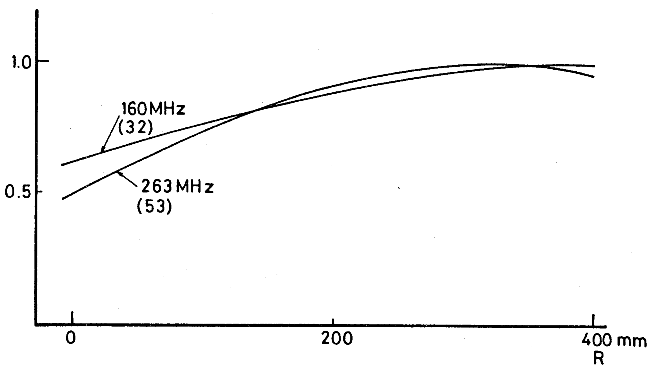


Fig.5. Radial voltage distribution of the acceleration cavity.

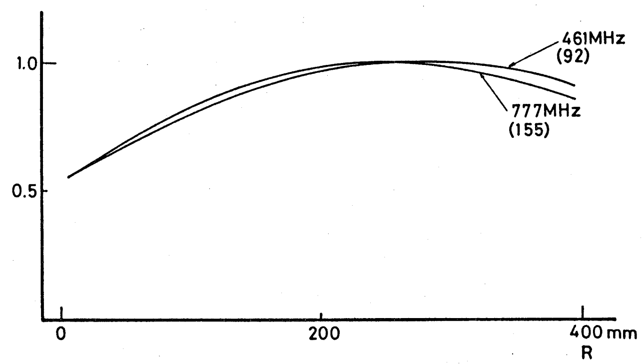


Fig.7. Radial voltage distribution of the flat-topping cavity.

## 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. 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. Up-down symmetry of the cavity is important to reduce unwanted leakage of RF power through the beam aperture. The cutoff frequency of the beam aperture (2m) is 75 MHz for up-down mode oscillation. The radiation from the aperture may perturb beam phase probes.

The same radial voltage distribution as that of the acceleration cavity is desirable to reduce radial oscillation.[2] The cavity is designed to produce radially increasing voltage distribution. The measured voltage distributions are shown in Fig. 7. Voltage distributions along the acceleration electrode are similar to those of acceleration cavity.

## References

1) A. Shimizu et al., "The RCNP Ring Cyclotron" in these proceedings.
2) T. Yamazaki et al., "Beam Quality Study in RCNP Six-sector Ring Cyclotron"; 11th Int. Conf. on Cyc. and their Appl. P.230 (1986).