# RF MODEL STUDY FOR A PROPOSED RING CYCLOTRON SYSTEM AT RCNP

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Abstract.- A model study for a variable frequency $H_{101}$ mode single gap RF cavity for the 1st ring of the new accelerator complex of RCNP has been done. Various characteristics of the cavity are measured and the problems related to the variable frequency single gap cavities are discussed.

1. Introduction.- Variable frequency $H_{101}$ mode single gap RF cavities with a tuning plate are being studied for the 1st ring and the 2nd ring of the cascade ring cyclotrons.[1] This accelerator complex has many RF cavities consequentry the RF system should be a synchronized MOPA system and RF phase error between these cavities must be kept below 0.1°. Accordingly inductive trimmers and electrical phase control systems are needed. To realize the single turn extraction, the RF voltage stability should be better than $10^{-4}$ and frequency stability be better than $10^{-6}$. The characteristics of the RF systems are given in table 1.

Table 1. Characteristics of the RF systems

| | 1st Ring | 2nd Ring |
|---|---|---|
| RF frequency | 20∿32 MHz | 20∿32 MHz |
| Harmonic No. | 4,6,8,12 | 4,6,8,12 |
| RF peak volt. | 400 kV | 500 kV |
| RF peak cur. (density) | 15 kA 50 A/cm | 15 kA 50 A/cm |
| No. of cavity | 2 | 4 |
| RF power | 150 kW/cavity | 200 kW/cavity |
| $\Delta V/V$ | $10^{-4}$ | $10^{-4}$ |
| $\Delta F/F$ | $10^{-8}$ | $10^{-8}$ |
| $\Delta\theta$ | ±0.1° | ±0.1° |
| $\Delta\omega/\omega\,(\Delta\phi)$ | $10^{-6}$ (±1°) | $10^{-6}$ (±1°) |

$\Delta V/V$; pk-pk noise/pk RF voltage
$\Delta F/F$; RF frequency stability
$\Delta\theta$ ; RF phase excursion
$\Delta\omega/\omega$; cyclotron frequency stability
$\Delta\phi$ ; beam phase excursion

A preliminary study of the RF cavities for the 1st and the 2nd ring was done with 1/10 scale models. The RF cavities for the 2nd ring are similar in structure to ones for the 1st ring. Sufficient data to design RF cavities of the 2nd ring may be obtained through the full-scale model study of the 1st ring.

2. Full-scale single gap cavity model.- A full-scale single gap cavity model of the 1st ring is designed on the basis of the 1/10 scale model study to make more detailed investigation. The model cavity is illustrated in fig. 1. The model cavity is set on its side as the beam direction is vertical. This model cavity is composed of many panel units fablicated in the factory. These panel units are made of 40mm × 40mm angle-iron and 1.5mm thick steel plates covered with 0.28mm copper lining. Good electrical contacts between panels are made by finger contacts. An estimated degradation of Q-values of the cavity caused by electrical contacts is less than 10%.

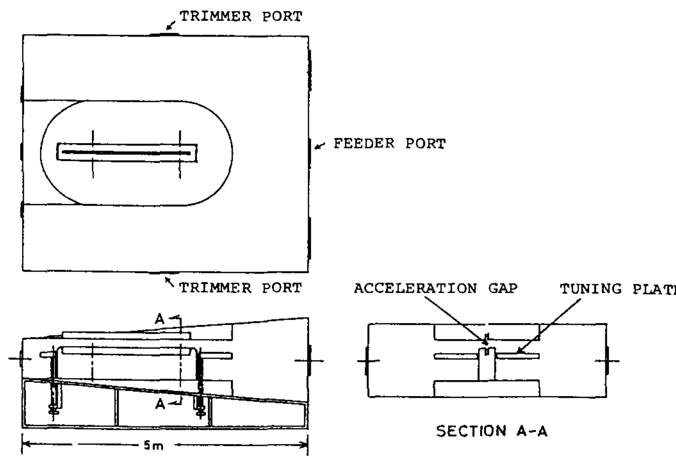


Fig. 1. Schematic view of the model cavity.

An oval tuner plate sliding on a stock changes the resonance frequency from 20 MHz to 32 MHz. The tuner plate is moved by two driving rods. Sliding contacts between movable elements and the stock are made by finger contact. RF current of this cavity has maximum at 20 MHz and estimated maximum current density of sliding contact is 50 A/cm. On the cavity wall eight ports are prepared to mount various assemblies such as an input or output coupling, fine tuning devices etc. Inductive coupling loops in various diameters from 15mm to 300mm are used as an input or output coupling of signal. The specifications of the model cavity are given in table 2.

Table 2. Specifications of the model cavity

| | |
|---|---|
| Resonance frequency | 20∿32 MHz |
| Resonance mode | $H_{101}$ |
| Acceleration gap | 150 mm |
| Radial beam aperture | 2100 mm |
| Maximum RF power | 5 kW |
| Size | 4900 mm$^L$×4000 mm$^W$×2000 mm$^H$ |
| Weight | 1 ton |

3. Resonance frequencies of the cavity.- Resonance frequency of the cavity was investigated by sweep oscillator method. Five resonancies labeled A, B, C, D and E are measured below 100 MHz for various position of tuning plate as shown in fig 2.

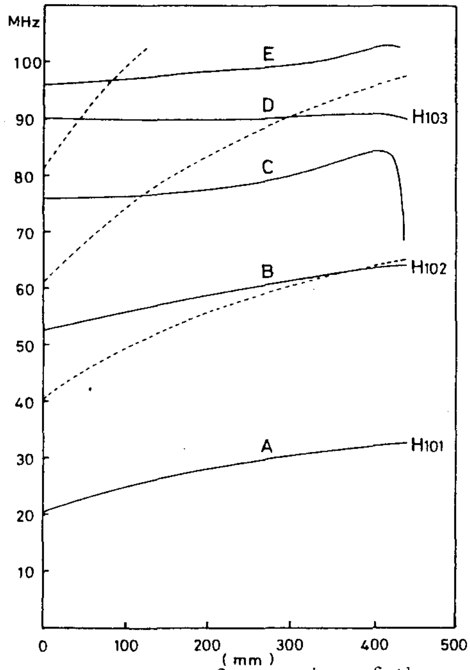


Fig. 2. Resonance frequencies of the cavity vs. position of the tuning plate.

The resonance labelled A corresponds to desired $H_{101}$ mode. The $H_{102}$ mode resonance and the $H_{103}$ mode resonance correspond to B and D, respectively. The $H_{103}$ mode resonance is deformed from that of a simple rectangular resonator. The $H_{201}$ mode resonance is observed around 85 MHz, exciting from another port indicated by an arrow in fig. 3. Under the condition of the self oscillation of the cavity, the modes of oscillation were determined by perturbation method and by measurement of the direction of magnetic flux with a vector voltmeter. The results are illustrated in fig 3. The resonances C and E relate to the RF oscillations on

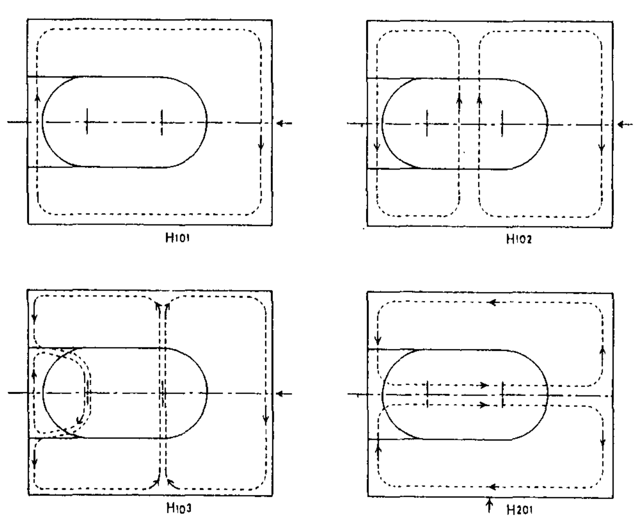


Fig. 3. Various modes of resonance. Broken lines show magnetic flux. Arrows indicate positions of coupling with which the cavity is excited.

the tuning plate. The 2nd, 3rd and 4th harmonic frequencies of $H_{101}$ resonance are also shown in fig. 2 with broken line. There are five crossings of resonance frequency below 100 MHz. Those multi mode resonances will be excited at the crossing i.e. on the special position of the tuning plate. The crossing of $H_{102}$ mode and 2nd harmonic of $H_{101}$ resonance is able to be eliminated by changing the ratio of radial width to hight of the cavity.

4. Voltage distributions in the gap.- The mearuement of the relative electric field strength in the gap for the $H_{101}$ mode resonance were performed with the perturbation method[2]. A block diagram of the measuring system is shown in fig. 4. The perturbing body ($30mm^{\Phi} \times 45mm^{L}$, polystyrene) hanged with string is driven 20mm/sec across the acceleration gap by a stepping motor. Perturbed resonance frequencies are

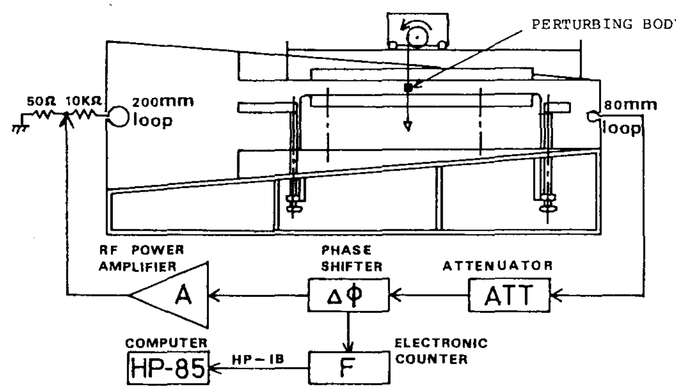


Fig. 4. Block diagram of the system used to measure field distributions in the gap.

measured every 101m sec. Gate time of the frequency counter was 100m sec. Relative voltage of the gap is calculated from the relation $V \propto \Sigma(\Delta f)^{1/2}$ where $\Delta f$ is frequency shift. The measurement were performed by desktop computer HP-85 and frequency counter with HP-IB system and data reduction is made automatically. The time required to make a measurment of one gap voltage was about 10 seconds (number of measurements is 100). The measurements of the field distribution in the gap are made every 100 mm for radial direction. The frequency shift at maximum electric field was 350 ~1500 Hz. Nominal frequency fluctuation of resonance was about 15 Hz during 10 sec. The temperature coeficient of the frequency of $H_{101}$ mode resonance was about +1kHz/deg around room temperature. This may be attributed to a sag of copper lining caused by the difference of expansion coefficients between copper and steel. The measured voltage distributions along acceleration gap are shown in fig. 5 for seven resonant frequencies.

5. Q-values for $H_{101}$ mode .- The circuit used to measure Q-values is shown in fig. 6. In order to reduce an effect of outer coupled shunt impedance and to measure precisely the intrinsic Q-values of the cavity, a weak coupled system with small size loops (15mm and 25mm ) are used. Q-value is obtained from the full width at half maximum of the resonance peak. The result is shown in fig. 7. The shunt impedance of this cavity is roughly proportional to Q-value or input impedance of the loop. The Q-value of this cavity has minimum at the lowest frequency (20 MHz) as shown in fig. 7. Thus maximum RF power is needed at the lowest frequency for excitation of same acceleration valtage. However, the necessary acceleration voltage is proportional to beam energy therefore the maximum acceleration voltage and RF power is

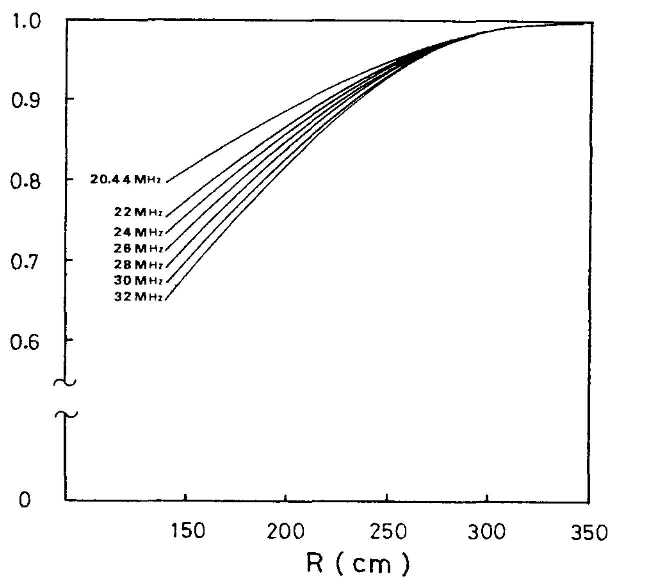


Fig. 5. Voltage distributions along acceleration gap. Values are normalized at the extraction radius.

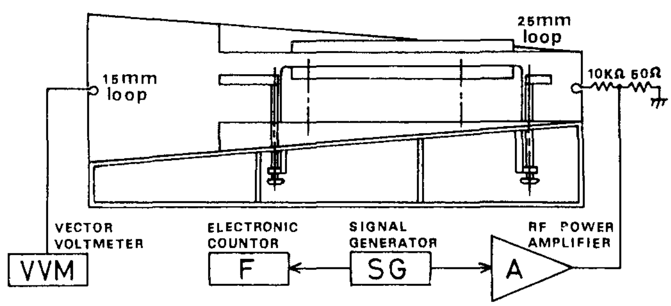


Fig. 6. Circuit used for measurment of Q-values.

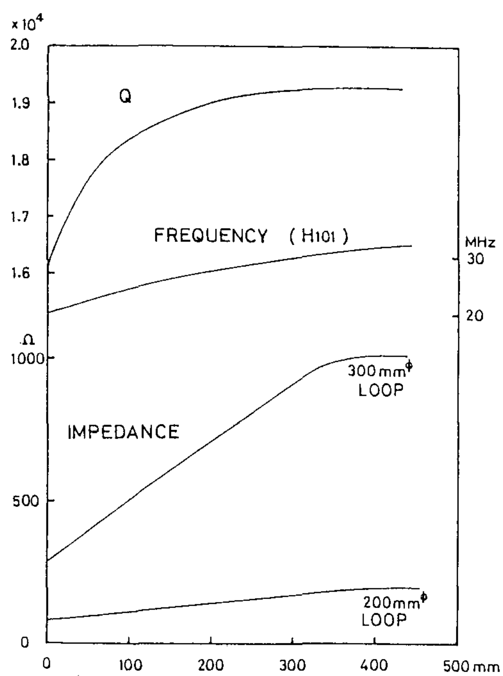


Fig. 7. Measured Q-values and input impedances of the cavity.

needed at 32 MHz. The estimated maximum RF power losses are 150 kW and 200 kW for the 1st ring and the 2nd ring, respectively.

More detailed studies of the cavity mentioned below are being carried out.

1) Design study of coupling circuit between final power tube (RCA 4648) and the cavity.
2) Design study of grid driving circuit of the final amplifier.
3) Measurement of shunt impedance of the cavity.
4) Design study of an inductive trimmer for the fine tuning system of the cavity.

## Acknowledgements

The authors wish to thank prof. M. Kondo for his encouragement and valuable discussions. They also wish to thank staff of RCNP for their support and encouragement.

## References

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