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Model Experiments for rf Structure of Kyoto University Superconducting Cyclotron

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The full scale model experiments for the rf structure of Kyoto University cyclotron were performed, and the characteristics obtained are described.

KEY WORDS: Superconducting cyclotron / AVF cyclotron / Isochronous cyclotron / rf structure of cyclotron

I. INTRODUCTION

The superconducting cyclotron is being developed at Chalk River[1] and at Michigan State University,[2] the model test for the superconducting magnet of the cyclotron was performed at the University of Milan,[3] and also proposals were presented by Berkeley[4] and Oak Ridge.[5] The idea of these machines is to adopted superconducting coils to the main field coils of isochronous cyclotrons. The using the high field generated by these coils lead to a reduction in physical size, and give promise of savings both in construction and operation costs.

The Kyoto University superconducting cyclotron is a prototype machine for establishing the basic feasibility of the superconducting cyclotron. The k-value of the cyclotron is 14 MeV and is a three-dee structure. The design studies are going on, and a superconducting coil is under construction at a company***, and the coil will be completed in march of 1980. The full scale model experiments for the rf structure were performed at Kyoto University recently.

II. rf STRUCTURE

In the design of high field cyclotron the multi-dee design is preferable because of a large energy gain per turn is obtained, that is required to produce enough orbit separation at ejection. In the three-dee design the beam is accelerated across six gaps between dees and copper sheaths covering the hills. The dees fit into the valleys of the magnet, and are mounted on inner conductors of coaxial tuners extending above and below the midplane of cyclotron. The upper and lower coaxial tuner and the

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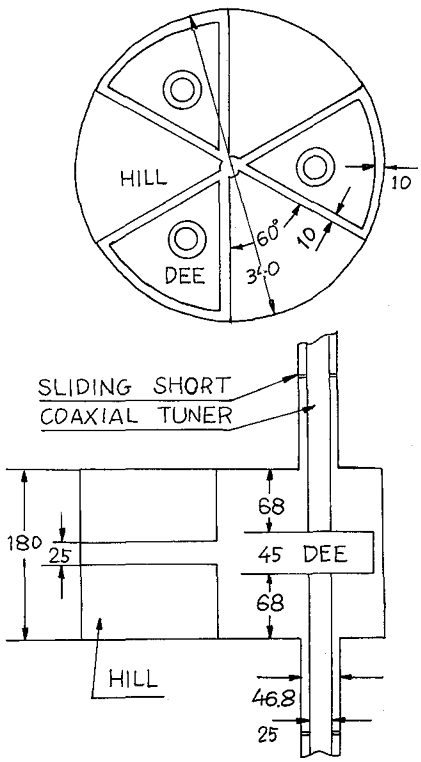

Fig. 1. Full scale model for rf structure of superconduction cyclotron. All are made of copper except sliding shorts. Sliding shorts are spring contacts made from phospher bronze sheet. (unit: mm).

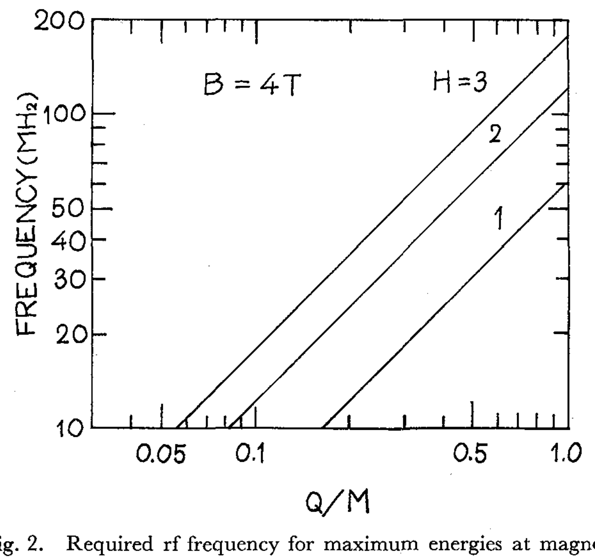

Fig. 2. Required rf frequency for maximum energies at magnetic field of 4 T. H is the number of harmonics operation, Q/M is the charge mass ratio of the ion.

dee, which is a lumped capacitive load, form a $\lambda/2$ resonator, and is tuned with sliding shorts of both tuners. The dees are excited with an adjustable capacitive couplers through 50 Ω coaxial lines from rf amplifiers. For fine frequency tuning the capacity of the dee is changed by a small movable capacitive coupler. In Fig. 1 the full scale model for the rf structure is shown.

The required rf frequency for maximum energies in 1st, 2nd, and 3rd harmonics operation as a function of the charge mass ratio Q/M of the ion are shown in Fig. 2. The rf phase difference between successive dees are 120°, 240° and 360° corresponding to 1st, 2nd and 3rd harmonics operation. In Fig. 3 the photograph of the model for rf structure is shown.

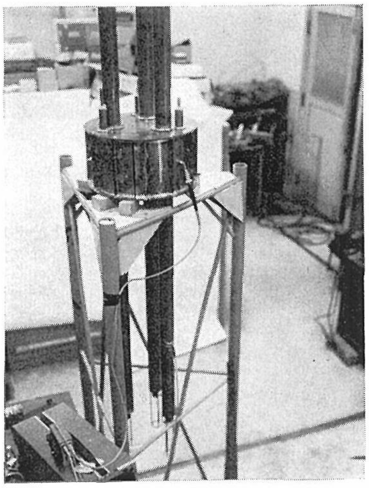

Fig. 3. Photograph of model for rf structure.

III. MEASUREMENTS

The frequency tuning characteristics were measured in the model. Frequencies as a function of the sliding shorts position are shown in Fig. 4. In this case both shorts are set at same distance from the dee. The capacitance is estimated from the following equations.

$$\frac{2}{\omega C} \approx Z_0 \tan 2\pi l/\lambda \qquad (1)$$

$$Z_0 \equiv 60 \ln B/A \qquad (2)$$

where C is the capacitance of the dee, ω is angular frequency, λ is the wave length, Z_0 is the characteristic impedance of coaxial tuner, B is the outer tube diameter of coaxial tuner and A is the inner tube diameter of coaxial tuner. The values of dee capacitance calculated from the equations are almost 25 pF at frequencies below 150 MHz which corresponds the tuner length is longer than 30 cm.

Figure 5 shows the frequency and dee voltage variation for the upper sliding short position while the lower is fixed. The dee voltage is maximum when both sliding

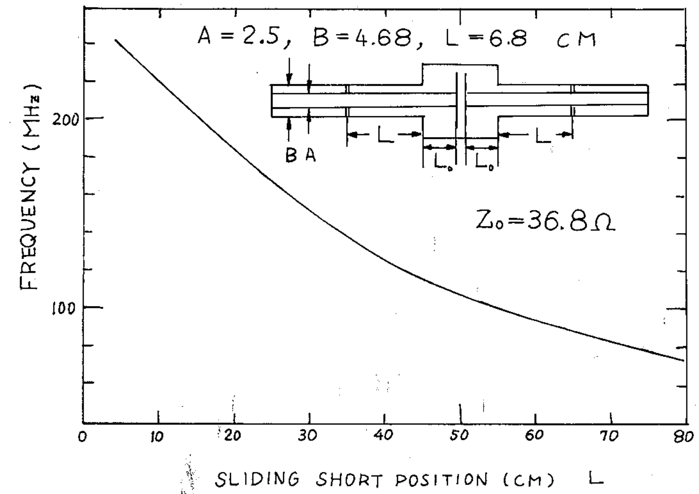

Fig. 4. Tuning frequency for sliding short position. Both shorts are set at same distance.

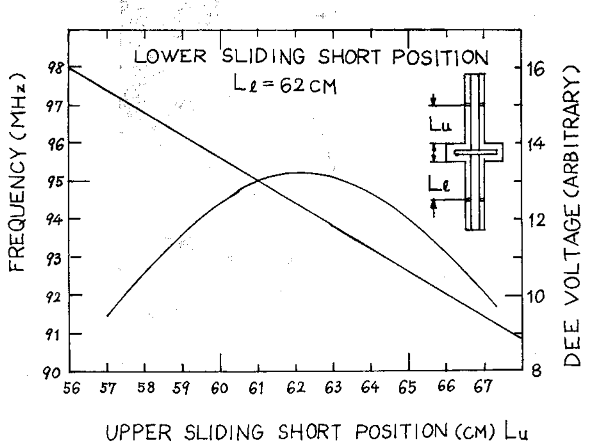

Fig. 5. Tuning frequency and dee voltage for upper sliding short position. Lower short is fixed.

shorts are at same distance, and decreases gradually with increasing the asymmetry. In Fig. 6 the frequency variation for fine tuner setting is shown. The fine tuner is a copper disk of 25 mm diameter.

The rf power to excite a $\lambda/2$ coaxial resonator is calculated from the following relations.

$$P = V^2/(2Z_s) \tag{3}$$

$$Z_s = (2/\pi) \times Q_0 Z_0 \tag{4}$$

where P is rf power, V is the peak voltage at the voltage loop, Z_s is the shunt impedance and Q_0 is the Q value of the resonator. The Q_0 measured was 2800 at 100 MHz, and Z_s is calculated to be 48 kΩ. The rf power to excite the dee up to 20 kV peak voltage is estimated to be 4 kW.

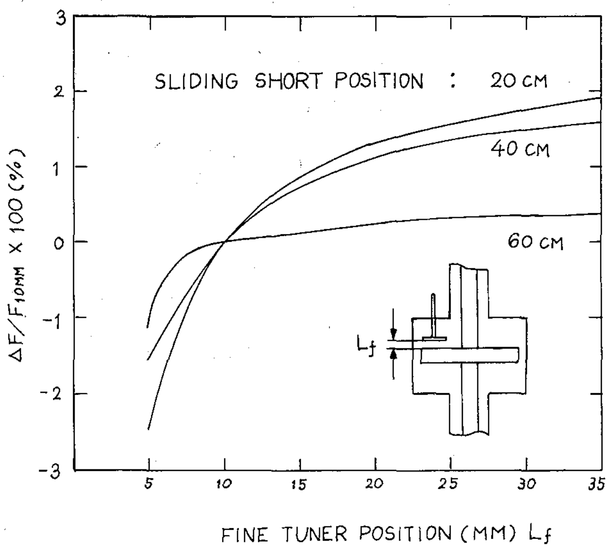

Fig. 6. Fractional variation of dee capacitance for fine tuner position. Both shorts are set at 20 cm, 40 cm, and 60 cm respectively.

The surface current at the sliding short is estimated to be 40 A/cm. The current is well in the controllable value by using the simple spring contact type short.

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