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MODELLING OF THE CHALK RIVER SUPERCONDUCTING HEAVY-ION CYCLOTRON RF STRUCTURE

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Summary

The characteristics of the Chalk River superconducting heavy-ion cyclotron rf structure obtained from one-tenth scale model experiments are described and the design of a full scale model under construction is outlined.

Structure

The Chalk River superconducting cyclotron[1] is a compact high field cyclotron and therefore a large energy gain per turn is required to produce adequate orbit separations at injection and extraction. This lead to a four sector design with the circulating beam accelerated across eight gaps between four dees, excited to 100 kV peak rf voltage, and a copper sheath covering the hills at ground potential. Figure 1 is a photograph of the accurate one-tenth scale model. The dees are "spiralled" to fit into the valleys with a minimum clearance of 30 mm at the inner radii and 40 mm at the outer radii. The azimuthal width at the outer edge (36°) is as large as possible to house the electrostatic deflector and reduced somewhat at intermediate radii to reduce the capacitive loading.

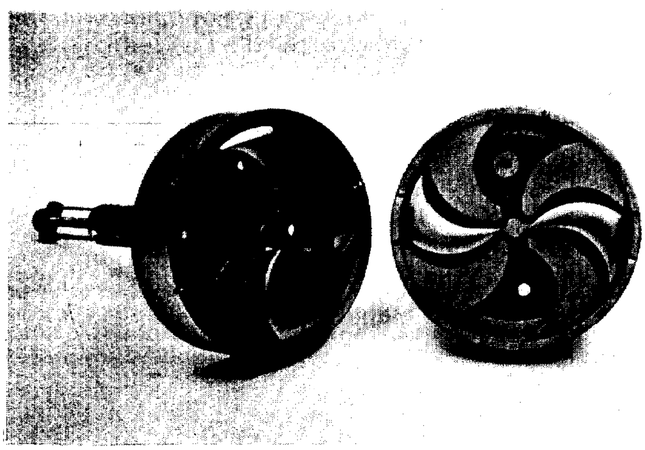

Fig. 1 Photograph of the one-tenth scale model.

Opposite dees are mounted on coaxial tuners extending above and below the midplane on the axis of the cyclotron, each being tuned to resonance with a sliding short. Capacitance between the dees in the central region couples the two circuits to form a system with 0-mode (in phase) and π-mode (out of phase) resonances at slightly separated frequencies. The wide energy range required, 3 MeV/u to 50 MeV/u, is then covered in an rf tuning range of 31 to 62 MHz by using both resonances and the second, fourth and sixth cyclotron harmonics.

The system is driven through a 50 ohm coaxial line terminated by an adjustable capacitor critically coupled to one dee to provide a matched load for the rf power amplifier.

Tuning Characteristics

The frequency tuning characteristics measured in the one-tenth scale model and scaled to full size are shown in Fig. 2. Cyclotron harmonic ranges covering the 3-50 MeV/u energy range are shown.

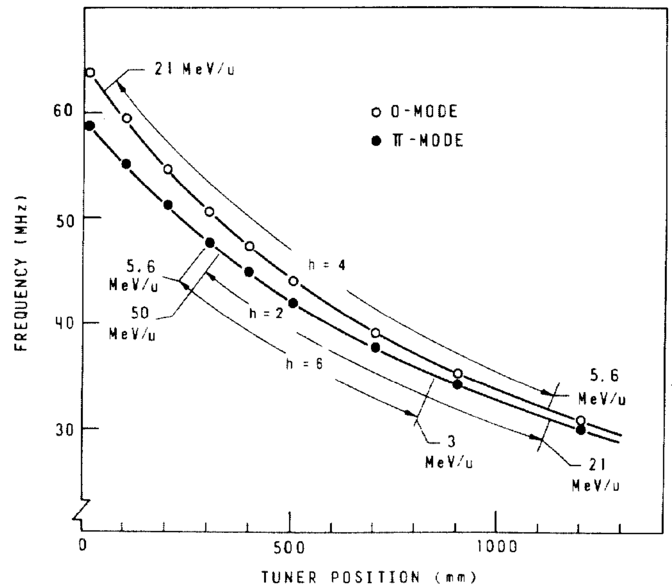

Fig. 2 Frequency tuning characteristics.

Figure 3 shows the resonator voltage variations for upper and lower tuner settings which keep the resonant frequency constant at 40 MHz. To maintain the resonators "balanced" and on frequency, the undriven-resonator tuner will be controlled by a voltage comparison between resonators and the driven-resonator tuner by a phase comparison between drive line and resonator.

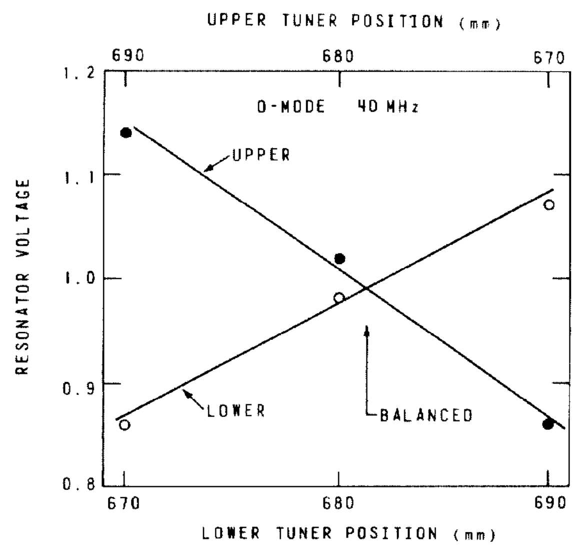

Fig. 3 Voltage "balance".

Asymmetries required for extractor electrodes and cryopumps introduce a difference in capacitive loading between the opposite dees of each resonator. Figure 4 shows the unbalance in voltage caused by a difference in capacitance as measured in the one-tenth scale model and scaled to full size. The expected maximum capacitive difference is about 0.3 pF which must be corrected - especially at the higher frequencies - if the voltage unbalance is to be acceptable. The full scale resonator will have two balancing capacitors with a range of

0-2 pF each.

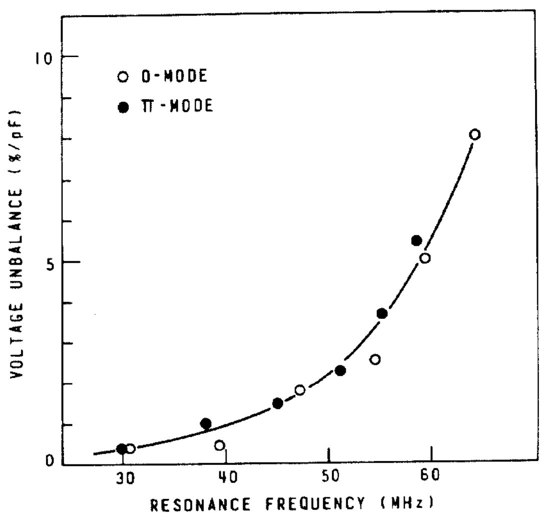

Fig. 4 Voltage unbalance caused by asymmetries.

Accelerating Fields

The dee voltage increases with radius because the tuners are at the centre. The size of this increase was investigated by "bead pulling"[2] in an earlier model with uniform width acceleration gaps and was about 20% at the highest frequency. This reduces the orbit separation at injection but with 100 kV peak rf voltage on the dees, the separation is adequate up to 50 MeV/u.

Power Estimate

The rf power required to excite the full scale structure to peak voltage, V, was estimated using $P = V^2/(2Z_s)$ and a value of Z_s scaled from that measured by the resistor method[2] in the one-tenth scale model. To eliminate errors from radiofrequency effects in the resistors, they were calibrated at 330 and 660 MHz using ideal quarter-wave coaxial resonators for which the parameters are known.

The one-tenth scale model results in Fig. 5 shows Z_s decreasing, hence the required power increasing, with decreasing frequency. In the cyclotron, the inner conductor of the tuner was decreased to 180 mm from the 190 mm corresponding to the model (the outer conductor is 280 mm diameter) giving the estimated values at the top of Fig. 5. With this change, the rf power required at all frequencies is then no more than the 98 kW estimated for 66 MHz.

The estimated surface current on the inner conductor at the sliding short is 5 kA/m of circumference.

Tuner Sliding Short

The usual clamping-type short is complicated — spring finger-contacts are simpler if they can be used. The V-I characteristic of a single spring contact of the commercially available type chosen, measured at 60 Hz in a vacuum, is shown in Fig. 6. The design maximum current of 5 kA/m at 60 MHz corresponds approximately to 12 A per contact at 60 Hz. This is well below the non-linear part of the characteristic, where temperatures increase, and an order of magnitude below failure. The contact force was about 0.2 N at a deflection of 0.5 mm - light enough to be moved without significant wear.

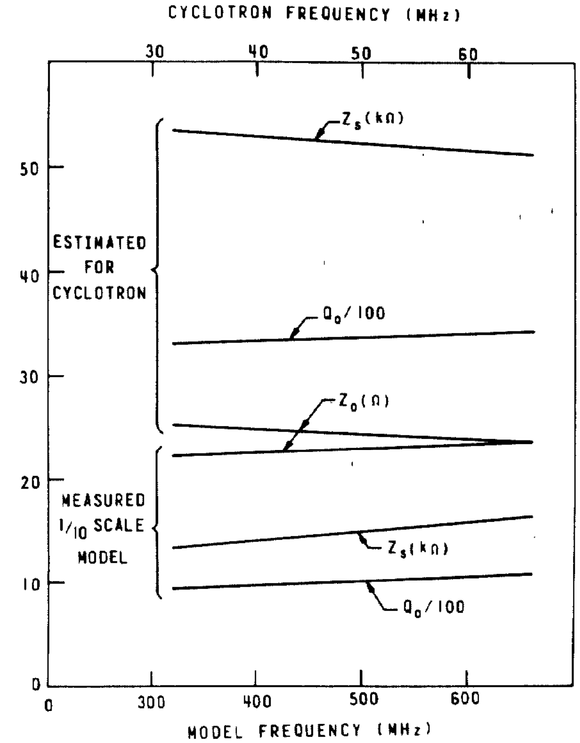

Fig. 5 Parameters measured in the one-tenth scale model and estimated for the full sized model, $Z_o = (\pi/2)(Z_s/Q_o)$.

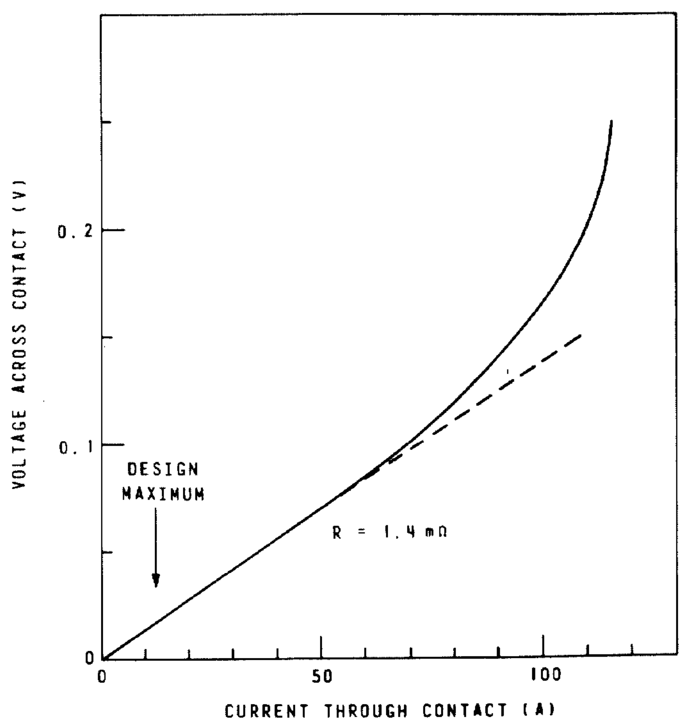

Fig. 6 V-I characteristic for one finger contact.

An rf test was carried out in a high-power quarter-wave resonator with an automatic frequency controlled tuning short fitted with these finger contacts. There was no indication of damage after 5 hours operation at design current and 50 hours at half current.

It seems therefore that a short with spring-finger contacts can carry the required current and be tuned under power.

High-Power Resonator

A section through one valley and dee of the full-sized high-power resonator in the magnet is shown in Fig. 7. The liner forms a continuous 2.4 mm thick welded-copper electrical ground plane and vacuum barrier between the high vacuum cavity containing the resonator and the rough vacuum behind. The 3 mm thick copper "window" in the cryostat wall joins the upper and lower liners and is bulged outwards to provide at least 40 mm separation from the dee.

The dee is joined by the web to the dee stem which is split axially - each half carrying one dee. Access to the stripper foil mechanism[1] and extractor electrode[1] is through the dee stem and web. The dee, web and stem are 3 mm thick welded copper assemblies cooled by water in tubes soldered to the inside. The dee stems are cantilevered from the outer ends of the tuners which extend just beyond the outer end of the magnet pole-pieces to allow the required sliding short travel of 1232 mm.

Additional access is provided through eight 100 mm diameter holes in the pole-piece at 500 mm radius. In Fig. 7, the lower hole contains the 50 Ω coaxial line to the drive capacitor. Other holes are used for two cryopumps[1], two diffusion pumps[1] and the two balancing capacitors.

Full-Sized Model

A full sized high-power model of the rf resonator is being constructed for testing in a dummy vacuum housing. It will be fitted with vacuum pumps, cooling system, control system and power amplifier for testing of all features not dependent on the magnetic field and will be ready for installation in the magnet when the field mapping[1] has been completed.

References

1. J.H. Ormrod, C.B. Bigham, J.S. Fraser, E.A. Heighway, C.R.J. Hoffmann, J.A. Hulbert, P.W. James, H.R. Schneider and Q.A. Walker, "Status of the Chalk River Superconducting Heavy-Ion Cyclotron", proceedings this conference.
2. E.L. Ginzton, "Microwave Measurement", McGraw-Hill (1957) p. 457.

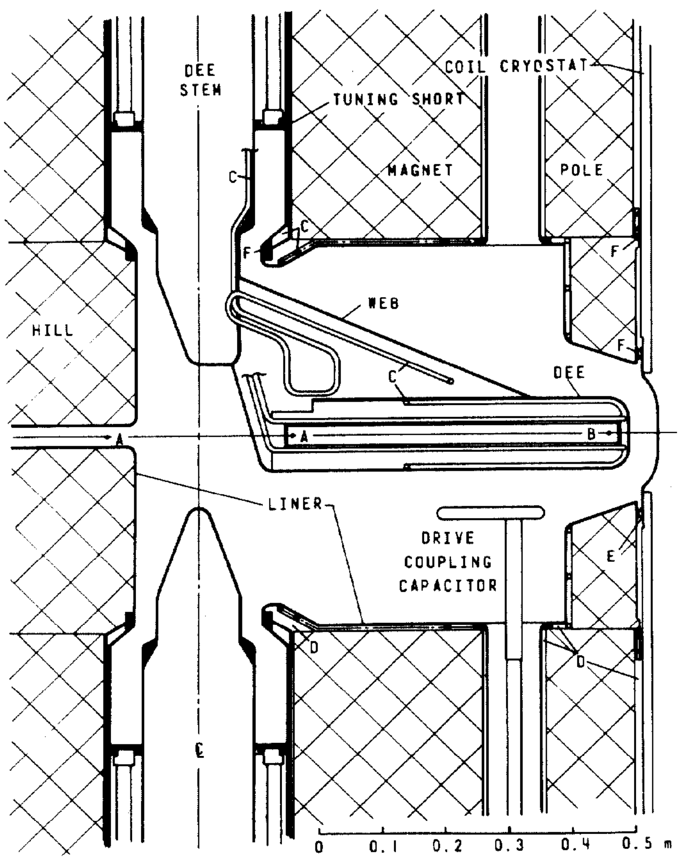

Fig. 7 The resonator installed in the magnet showing a hill section on the left and a valley section on the right. Letters indicate A - inner orbit, B - extraction orbit, C - water cooling, D - rough vacuum spaces, E - rf contacts around the pole and F - vacuum seals between rough vacuum and high vacuum.