THE CHALK RIVER SUPERCONDUCTING HEAVY-ION CYCLOTRON RF STRUCTURE

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ABSTRACT

The rf structure for the Chalk River superconducting cyclotron is described and the commissioning status reported.

GENERAL DESCRIPTION

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 separation at injection and extraction. This led 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 liner covering the hills at ground potential. The rf characteristics were determined by one tenth scale modelling[2]. Figure 1 shows a section through the structure as it will be when installed in the magnet. Initial tests have been conducted in a dummy vacuum vessel (see below).

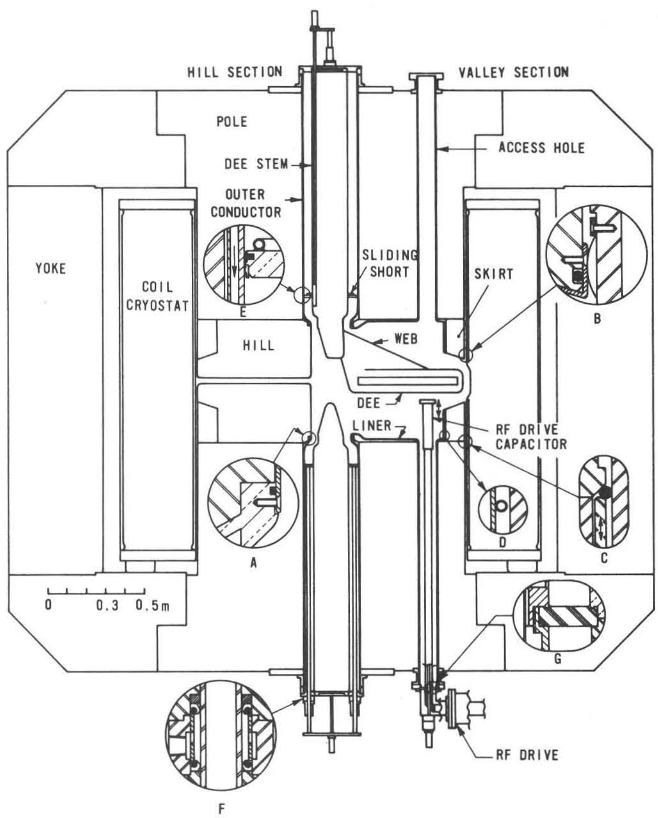

Fig. 1 Sectional view of the rf structure installed in the magnet showing a section through a hill on the left and through a valley on the right. Insets show the details of rf contacts and vacuum seals.

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 met within 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.

LINER

The liner serves as the outer conductor of the rf structure and the vacuum barrier between the beam cavity and the rough vacuum around the hills. It is constructed from 2.5 mm thick high conductivity (alloy 110) copper. Each hill sector was shaped and welded over a machined aluminum form and then welded into the valley floor and skirt cover. The tubes lining the eight 100 mm diameter valley access holes through the poles at 500 mm radius are welded into the liner. The outer conductor of the tuner must be installed from the outer end of the pole because of the noses on the hills. It is joined to the liner by a mechanical joint with an O-ring vacuum seal and finger contact rf seal shown in detail A on Fig. 1.

The rf cavity is completed across the midplane by the inner wall of the cryostat which has copper bulges welded in to provide more clearance at the tips of the dees. The liner has an O-ring vacuum seal to the skirt and presses against spring contacts to make the rf contact to the cryostat wall (detail B). The high vacuum seal between the skirt and the cryostat is made by an O-ring around the skirt (detail C). This ring is forced out to seal the joint by a backing ring actuated from the outer surface of the pole after the pole is in place.

Cooling tubes (4.8 mm ID) are soldered to the pole side of the liner with one circuit in each valley (detail D). Dee voltage probes are built into one side of each valley with a solid sheath coaxial line leading out the valley access holes. There is also a temperature monitor at a different location in each valley.

OUTER CONDUCTORS

The outer conductors of the tuners are double walled to provide a cooling water annulus and fit into 300 mm diameter holes through the centre of the poles. They were fabricated from sheet, rolled and welded, and with inside bore machined to a good surface and 0.1 mm accuracy for the sliding short contacts. There is a mechanical joint to the liner at the inner end (detail A) and rough vacuum seal to the pole at the outer end.

DEES AND DEE STEMS

Figure 2 shows a photograph of the lower liner and dees. The dees are "spiralled" to fit into the valleys with a minimum clearance of 30 mm at the inner radii and 36 mm at the outer radii. The azimuth width at the outer edge (36°) is as large as possible to house the electrostatic deflector and is reduced

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somewhat at intermediate radii to reduce the capacitive loading.

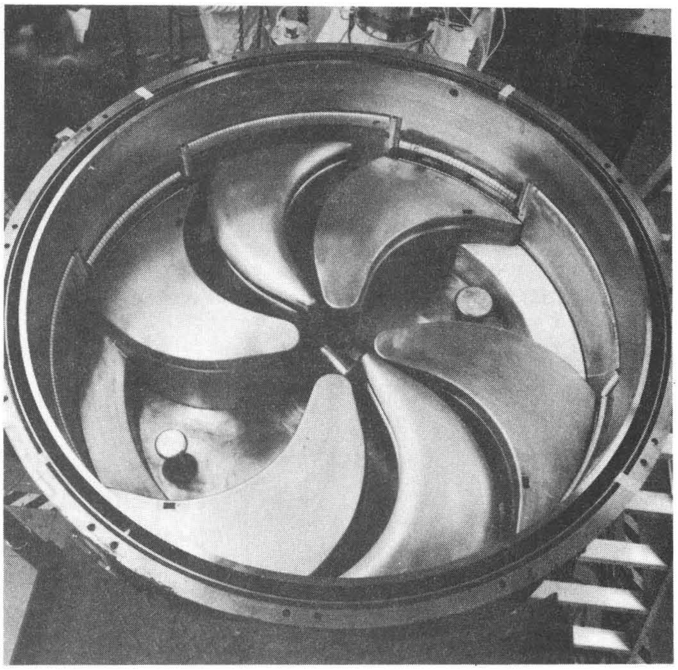

Fig. 2 Photograph of the lower half of the resonator installed in the dummy vacuum vessel showing the liner, two dees and the mock-up of the inside wall of the coil cryostat. The rf drive capacitor is in the valley on the left and the balancing capacitor on the right. The spring contacts between upper liner and cryostat are visible, a similar set are hidden by the lower liner.

Figure 3 is a photograph of one of the dees which are made from 3.1 mm thick high-conductivity copper (alloy 110). Upper and lower halves were pressed and hand formed over a machined steel die and then were welded together along the outer radius and to the web along the top and at the inner limit of the beam gap.

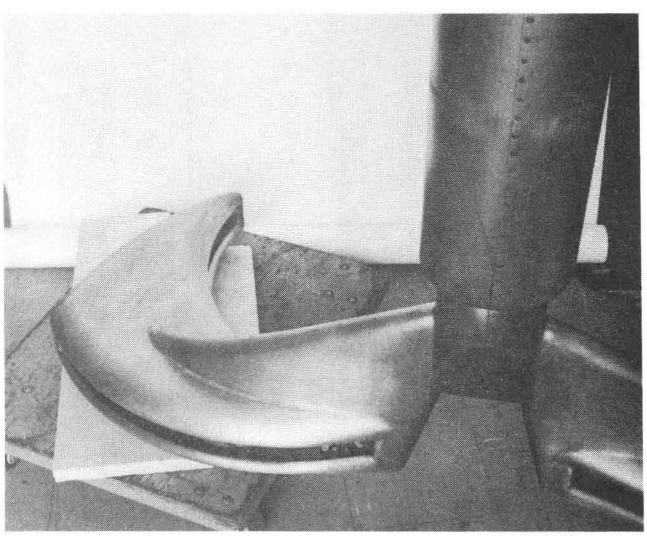

Fig. 3 Photograph of one dee showing the web which connects the dee to the dee stem and the midplane beam gap.

The web joins a dee to each half of the stem which is split longitudinally for access during assembly. Each dee is fitted with three cooling circuits: web, upper dee and lower dee. These tubes are also soldered inside the dee stems and cool the stem walls. The stems were rolled from sheet copper and the outer surface machined to 0.1 mm accuracy for the sliding short contacts.

The dee stems are supported by the flange sealing the outer end of the outer conductor. This flange is shimmed to centre the dee stem in the outer conductor and to position the beam gap at the midplane. There are two temperature sensors mounted at different locations in each dee.

TUNER

The sliding short tuners are water cooled copper plates moved by two push rods through vacuum seals at the outer ends of the tuner. Rf connection to the tuner walls is made with spring contacts[2]. (See detail E of Fig. 1.) Each tuner has a loop rf pick up and a temperature sensor.

The vacuum seals on the push rods are double chevrons with a guard vacuum between[3] (detail F). The tuner is actuated by a dc motor and screw drive connected to either a manual or automatic frequency control circuit.

RF DRIVE

The rf drive line (Fig. 1) passes through one of the lower valley access holes to a variable capacitor coupling to one of the dees. The capacitance is variable by a factor of two (0.5 - 1 pF) to allow critical coupling over the full frequency range. This is

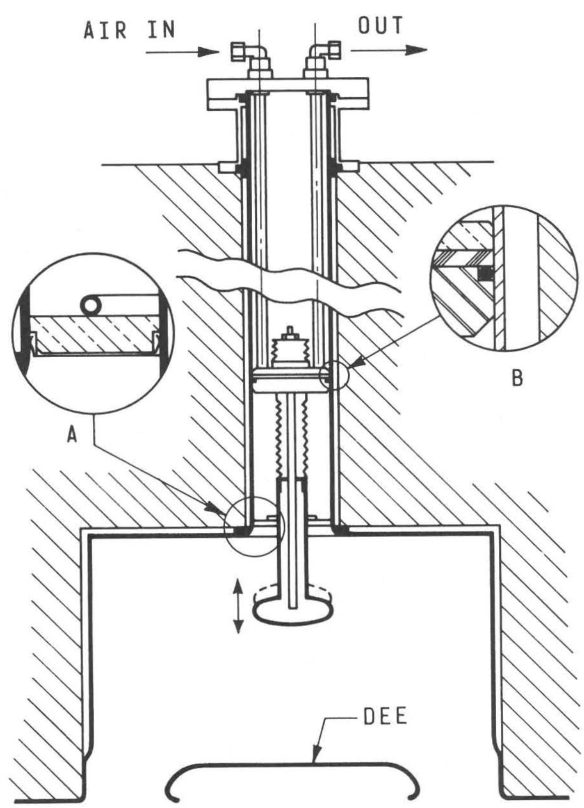

Fig. 4 An azimuthal sectional view of the fine tuner assembly installed in one of the valley access holes.

accomplished using a section of bellows in the inner conductor and a motor drive to operate a screw at the elbow end. The vacuum window is a teflon disk (detail G). Air cooling is provided to the centre conductor through the motor drive assembly. A 5" Heliax flexible drive line is used to connect to the 100 kW amplifier.

FINE TUNER

A fine tuner is located in a valley access hole (see Fig. 4). It is a pneumatically operated variable capacitor with a range of ± 0.02 pF. It is operated by air pressure in the range 1-2 atmospheres by balancing the force on unequal area bellows, one in the vacuum and one in the atmosphere. The air pressure is controlled by solenoid valves operated by the AFC circuit. The valves always pass some air to cool the capacitor.

BALANCING CAPACITOR

Although the resonator has basic four fold symmetry, each dee is in fact different and the cryopump housings partially fill two valleys. These differences can cause side to side differences in dee voltages[2]. Two balancing capacitors have been installed, one up and one down, on the low capacitance dee of each pair to correct the asymmetries. The assembly is shown in Fig. 5. The capacitor is varied with a motor driven screw and has air cooling in the main shaft.

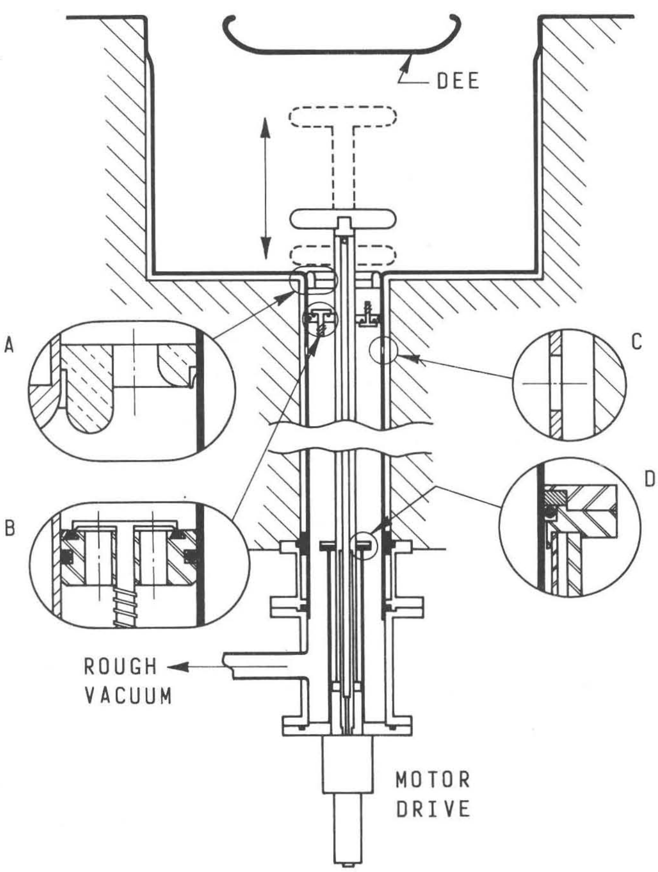

Fig. 5 An azimuthal sectional view of one of two balancing capacitor assemblies installed in one of the valley access holes.

The shaft has a double O-ring seal with rough vacuum between. The space between the liner and the pole is also pumped through apertures in the side of the copper tube.

Since the liner is not strong enough to withstand more than about 10 kPa differential pressure, it is protected by four spring loaded valves built into the vacuum barrier of the balancing capacitor. These will vent either way if the pressure differential rises above 5 kPa.

VACUUM

The vacuum pressure for negligible charge exchange of ions during acceleration should be less than ∿ 0.07 mPa but for rf testing, pressures in the 1 mPa range are adequate. Provision is made in two valleys for cryopumps to operate at 5 K, each with a pumping speed ∿ 1500 L/s. Helium leakage will be pumped by diffusion pumps on two of the valley access holes each with an effective speed of ∿ 50 L/s.

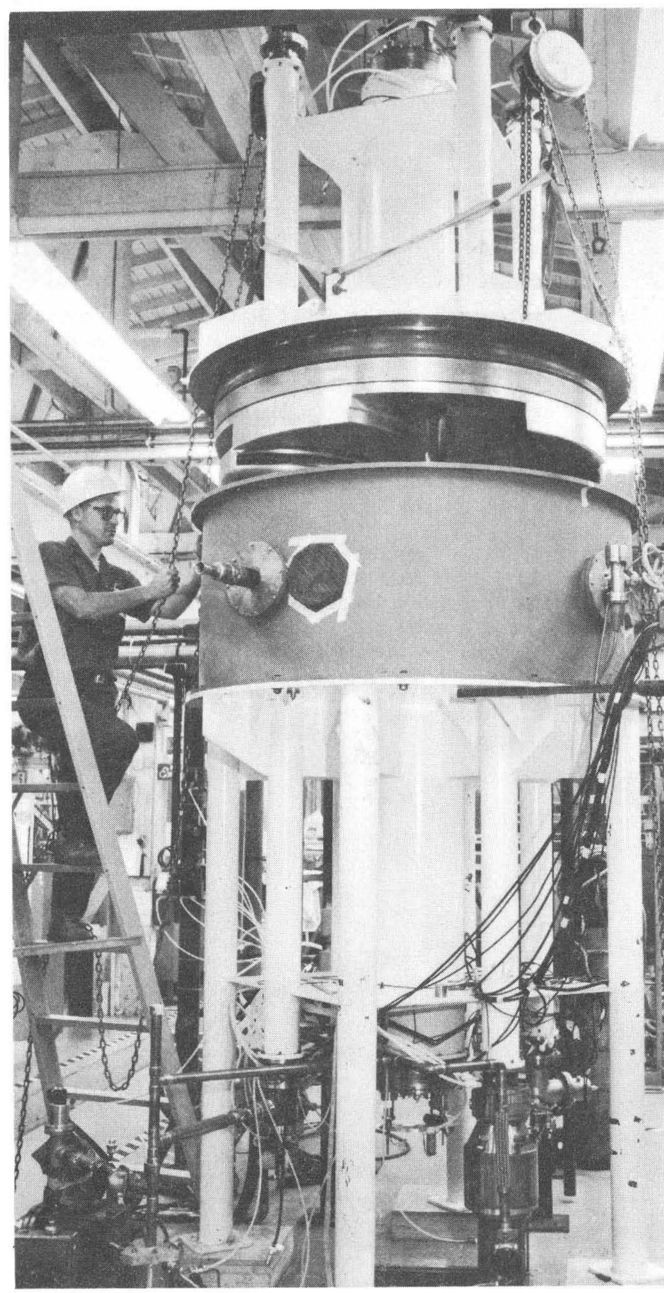

Fig. 6 Photograph of assembly of rf structure in the dummy vacuum vessel for high power tests out of the magnet.

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INITIAL TESTS

For initial tests, the rf structure is housed in a dummy vacuum vessel shown in Fig. 6 which mocks up the essential features of the magnet poles and cryostat inner wall. A 100 L/s turbo-molecular pump and a 4" liquid nitrogen trapped diffusion pump on two of the valley access holes pump the high vacuum volume. A 2" diffusion pump and mechanical pump pump the rough vacuum volume and also back the high vacuum pumps. There is no valve in the turbo-molecular pump line so that no significant pressure differential can develop across the liner. An ion gauge monitors the pressure in the high vacuum region through a port at the mid-plane.

RESONATOR RF CHARACTERISTICS

The tuning curves and quality factor, Q, were measured at low power with a network analyzer. With the structure excited through the drive capacitor and the transmission measured through the dee voltage probes, the resonator tuners were adjusted until 0 and π-mode resonances were equal in amplitude. This ensured that the voltages on the two resonators were equal[2]. A reflection measurement was then made to adjust the drive capacitor for a match. The tuning curves for the two modes are shown in Fig. 7 with cyclotron harmonics and ion energy ranges indicated. These are essentially identical with predictions from the one-tenth scale model experiments[2].

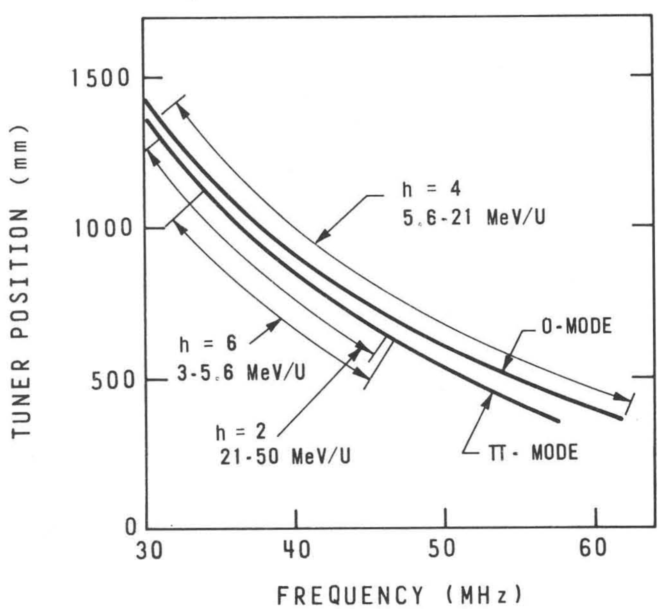

Fig. 7 Tuning curves showing tuner position (distance from midplane) vs frequency for both 0 and π-mode resonances. Cyclotron harmonic numbers and final energy range are also shown.

The matched or loaded Q obtained from measurements of the resonance width ranged from 1600, the value predicted from the one-tenth scale modelling, up to 2300. This indicates that the rf power required to reach 100 kV will be less than the predicted 100 kW for most of the frequency range.

HIGH POWER TESTS

Initial experiments showed that the first multipactoring levels occured at less than 1 W rf power level and that a fast turn-on would be required to break through. To do this, the rf drive to the main amplifier was modulated by a circuit that switched the drive on in $\sim$ 5 μs and held it on for 100 μs allowing the resonator to fill and the reverse power to drop. If the reverse power remained low, the drive stayed on. If multipactoring or arcing occurred and the reverse power remained high, the drive switched off for 0.1 s and then on again.

This circuit broke through multipactoring if the vacuum pressure was below $\sim$ 4 mPa and once started, operation continued without breakdown to pressures $\sim$ 10 mPa. The best continuous operation was up to a power level of 15 kW at 50 MHz with an estimated peak dee voltage of 50 kV, one-half the nominal rating. The maximum temperature rise observed was 30°C on a web. The frequency shift up to this power level was $\sim$ 40 kHz, which shows that temperature effects cause shifts several times the resonance width of $\sim$ 25 kHz. Retuning during power increase is required to keep the resonator on the fixed synthesizer frequency.

Testing was terminated to disassemble and inspect the structure for suspected damage to one sliding short tuner. This turned out to be a partial failure of the contacts on one tuner and is believed to have been caused by a poor fit. This will be improved in the next tests. There was no indication of high power problems in the rest of the structure.

ACKNOWLEDGEMENT

It is a pleasure to acknowledge the technical assistance of M.R. Cox and K.A. Dobbs.

REFERENCES

1. J.H. Ormrod, C.B. Bigham, K.C. Chan, E.A. Heighway, C.R. Hoffmann, J.A. Hulbert, H.R. Schneider and Q.A. Walker, "The Chalk River Superconducting Cyclotron", Proceedings this conference.

2. C.B. Bigham, "Modelling of the Chalk River Superconducting Heavy-Ion Cyclotron Rf Structure", IEEE Trans. NS-24, 1777 (1977).

3. P. Shatford, private communication (1976).

** DISCUSSION **

G. DUTTO: We heard this morning from Resmini that he would not like to have the stripping foil in a valley. Do you not see any inconvenience in servicing the stripper within the dee?

C. BIGHAM: Yes, but the best access is through the tuner stem, so the stripper must be inside the dee. The MSU tuner stem is not in the centre. Another consideration is that our stripper need only move radially—the MSU stripper must move azimuthally as well, and so is best in a valley with access through a central hole in the pole.