RF system for a proposed heavy ion cyclotron*

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The separated-sector isochronous cyclotron proposed by the Oak Ridge National Laboratory[1] would accelerate any ion of any element; heavy ions with $q/A \geqslant 0{\cdot}15$ would be accelerated to 7·5 MeV/a.m.u. and protons to 300 MeV. Ion orbit frequencies range from 0·5 to 10·0 MHz. The heavy-ion cyclotron is a ring structure of four-sector magnets with four rf cavities placed between them. Two cavities operate on the fundamental rf, variable from 10 to 30 MHz. Two other auxiliary cavities operate on the rf second harmonic; their phase can be adjusted for either 'flat-top' or 'peaked' modes of ion acceleration. Each cavity is a $\lambda/2$ TEM resonator, with the centre conductor protruding axially from both sides of the dee. An array of movable panels provides the 3:1 tuning range. An rf power amplifier on each cavity provides up to 400 kW to produce 250 kV on the fundamental dees, and up to 75 kW for 65 kV on the harmonic dees. A quarter-scale model cavity has been fabricated and the rf system is being optimised.

The rf system of the heavy-ion cyclotron is required to accelerate ions with orbit frequencies in the range of 0·5 to 10 MHz and to provide about a million volts of potential gain per revolution. Flat-topping of the waveform is desired for maximum beam phase acceptance concurrent with high extraction efficiency and minimum energy spread in the extracted beam.

An rf system tunable over the full ion frequency range is impractical; however, with the 10 to 30 MHz tuning range and the 36° dees reasonable utilisation of dee voltage is possible on various ion frequency harmonics. For harmonic numbers 3, 4, 5, 6, 7, and 15, the voltage gain per turn is about 750 to 1000 kV when the dee-to-ground rf voltage is 250 kV.

With open valleys 45° wide between the four magnet sectors, there is ample room for the rf cavities; restrictions on electrode-to-ground clearances are due to tuner design only. The use of the $\lambda/2$ resonator structure further reduces the dee-to-ground capacitance in each cavity. Characteristics of the two main cavities operating on the rf fundamental and two smaller second harmonic cavities for shaping the accelerating pulse are listed in Table 1. The main dees, Fig. 1, are trapezoidal with δ-shaped stems protruding axially from both top and bottom; there is a 3-in clearance to the outside walls of the cavity. The second harmonic cavities are similar except the azimuthal

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Table 1: CHARACTERISTICS OF RF CAVITIES

	Main	*Harmonic*
Frequency range (MHz)	10–30	20–60
Dee voltage peak rf (kV)	250	65
Rf excitation (kW)	350	65
Overall height (cm)	560	280
Beam aperture (cm)	5	5
Accelerating gap (cm)	7·5	3·75
Width of dee		
Radial (cm)	254	254
Azimuthal (deg)	36	18

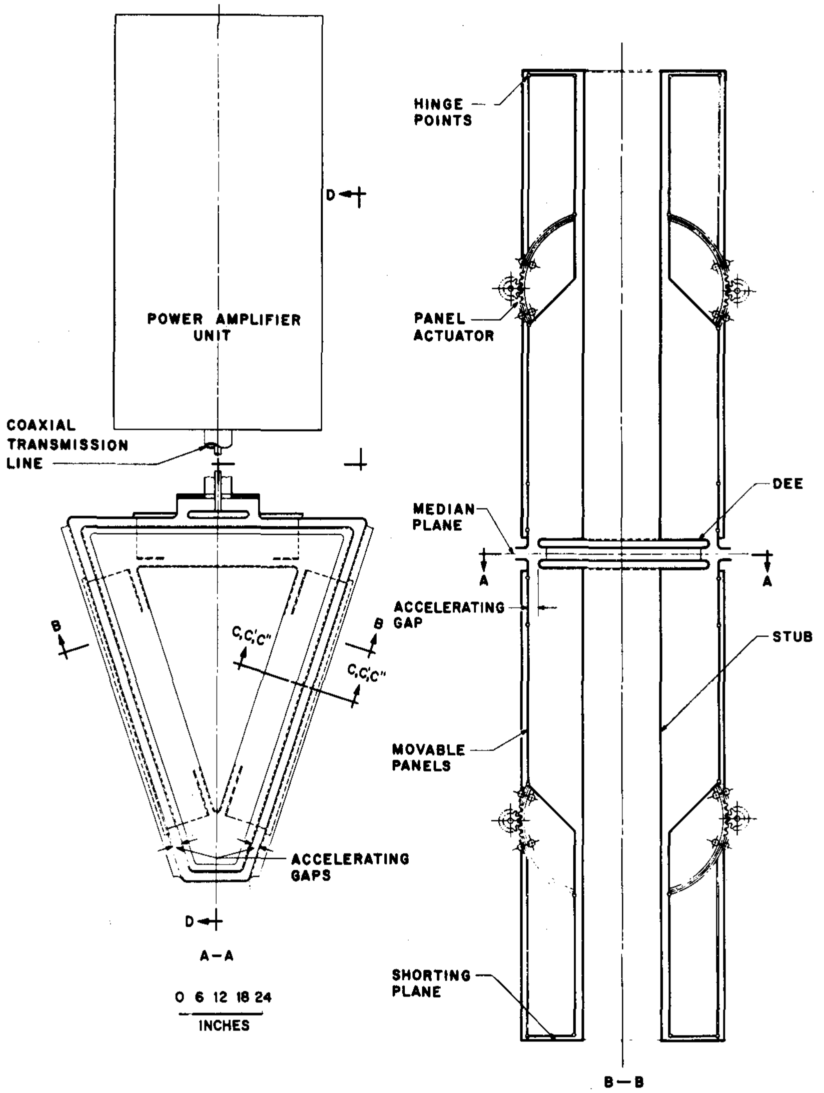

Fig. 1. Sections of a main cavity showing arrangement of the dee, dee stem, and tuning panels

dimensions and the overall height are half scale. Tuning is accomplished by redistributing the capacitance along the dee stems with the movable panels shown in Fig. 2.

Each cavity tunes as an LC circuit with a constant L/C ratio. Shunt resistance is nearly constant over the entire range. The cavity is capacitively coupled to a power amplifier by a drive capacitor at the outer edge of the dee. A small trimmer capacitor will probably be added to this region for fine tuning.

The optimum dimensions, Table 1, have been determined by extensive design and model studies. A quarter-scale model of an earlier configuration was fabricated and tested. Although its shunt resistance was less than that expected on the optimum configuration, the model confirmed the method for predicting cavity characteristics. Most important, it was shown that the rf

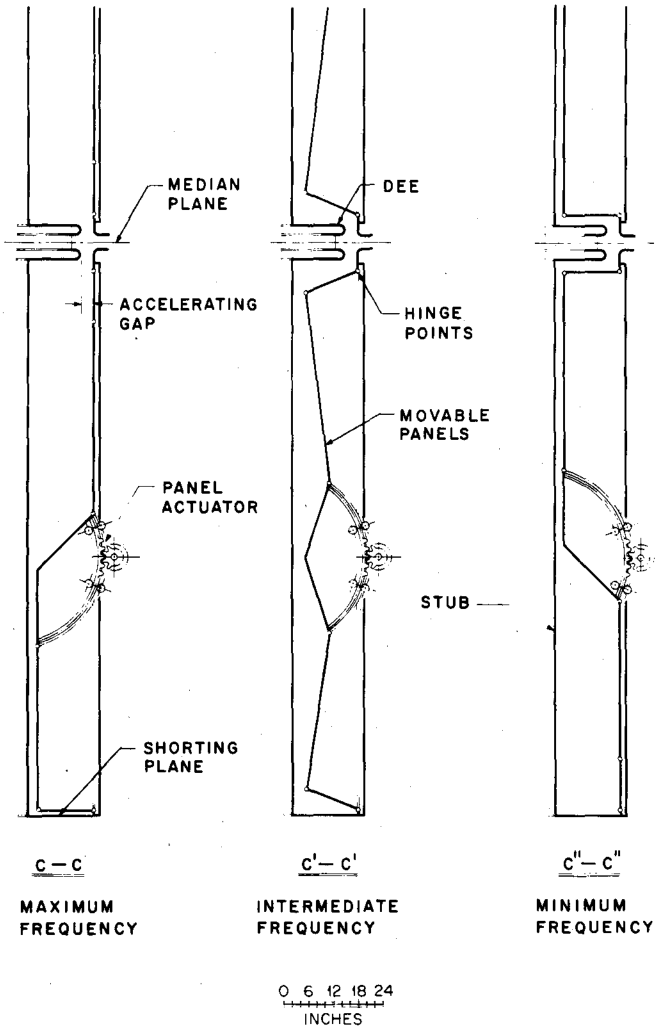

Fig. 2. Section of an array of tuning panels showing method of varying impedance along the dee stems

voltage along the accelerating gap is nearly constant with respect to machine radius, and that a substantial unbalance of the six sets of tuners does not alter the normal cavity characteristics.

Each of the four rf cavities is driven by an individual power amplifier. An RCA-4648 tetrode or equivalent high gain amplifier stage with a distributed amplifier type driver stage will be used for the main cavities. The harmonic units will be similar but with a much smaller power tube. All four power units will be controlled by an rf drive signal from a single master-signal generator via an array of signal dividers, phase shifters, and frequency doublers, where applicable. Closed loop amplitude and phase control are included.

When the flat-topped mode of acceleration is used, the second harmonic cavities operate 180° out of phase with respect to beam pulses so that the effective voltage gain per turn is reduced by about 25%. When maximum voltage gain per turn is required, and narrow phase width is tolerable, the harmonic cavities are operated in phase with the beam pulses.

Precision amplitude and phase control of the rf voltage on each cavity with respect to each other are vital to successful application of flat-topping. Instrumentation with sufficient resolution to measure phase errors as small as 0·1° or voltage errors as small as 0·01 are available; however, such measurements on an absolute basis will be difficult. It is expected that an elaborate system for observing beam pulse characteristics will be a necessary part of the required instrumentation.

REFERENCES

1. Martin, J. A., *et al.*, Proceedings of this Conference p. 41.