SOME RF SYSTEMS FOR CYCLOTRON MESON FACTORIES

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All the following studies apply to accelerators designed to produce 100 μA at 700 MeV.

The Dee-in-Valley Isochronous Cyclotron

This design is a six-sector version of the 50 MeV machine at UCLA[1)], with pairs of dees operating out of phase in opposite valleys at 8.7 Mc/s (see Fig. 1). The gain per turn is 2.6 V (where V is the peak dee voltage) at large radii and becomes progressively greater at small radii. The tapered dee has a "stretching" action which makes it possible to achieve 85% of the center voltage at the outer beam radius. It is, in effect, a non-uniform line with low capacity per unit length in spite of its size. The design dee voltage was taken as 180 kV peak on each dee, and, assuming 75% efficiency, the total d.c. input power was calculated to be 450 kW. The beam will add an extra 100 kW for every 100 μA of accelerated ions.

These figures were checked on a 1/6 scale model of one section fabricated from commercial sheet copper and with crude tolerance; the input power was 520 kW. The RF generator was a simple tuned-plate, tuned-grid oscillator using an Eimac 35T with the model dee serving as the plate circuit. The efficiency was found from the color of the anode. This method measures the shunt impedance, which is the pertinent parameter. The Q is not directly involved and was never measured.

The full-scale RF generator is envisaged as a master-oscillator-amplifier chain feeding four focused-beam type tubes such as the RCA 6949. Loop coupling is indicated

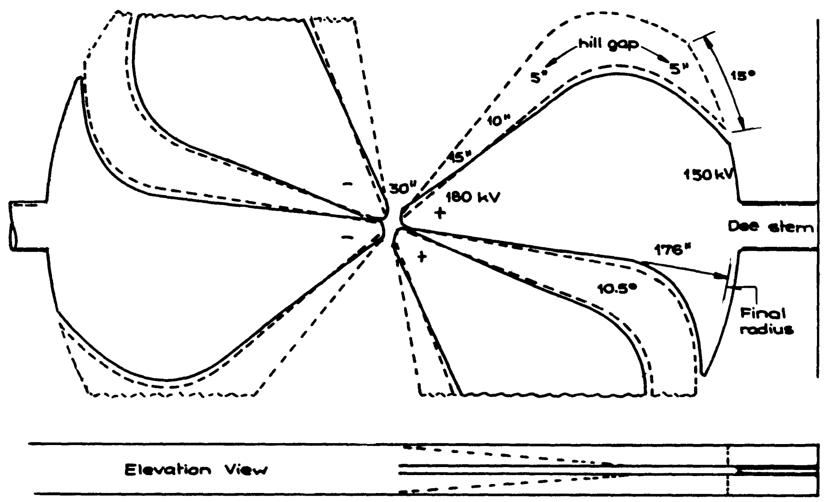

Fig. 1 Relative dimensions of dees and stems for the isochronous cyclotron as determined from model studies.

rather than a direct tap on the stem, since this minimizes transients on the lines and allows more flexibility in remote handling.

The Dee-in-Valley Synchro-Cyclotron

With the removal of duty-cycle limitations[2], the often considered union of spiral ridges and frequency modulation looks very attractive, especially so if the dees are placed in the valleys. The combination of reduced frequency range and lower capacity makes it very feasible to increase the dee voltage and corresponding repetition rate. Henrich, Sewell and Vale[3] measured beam versus dee voltage and found that $I \sim V^3$. Simple arguments support this data. Due in part to the open type ion source, a dense localized space charge sheet of ions exists in the center of a synchro-cyclotron. Potentially useful ions are repelled vertically; those that are turned back toward the median plane by magnetic forces constitute the useful beam. Two important time intervals are involved : a) the time the ion spends in the dense space charge region (which in rough approximation determines the vertical impulse), and b) the time of flight before being "caught" by the magnetic focusing force. Both times vary as $1/V$. The space charge density is proportional to I/V (where I is the beam current). Hence the ion current that penetrates well into the dee in normal cyclotron fashion varies as $1/V^3$. This state of affairs occurs at the beginning of every pulse, and since the pulse rate varies as V, the total dependence might be as high as V^4 if all other factors such as capture efficiency, source efficiency, etc. remained constant. It is worthy of note that variations in source geometry have been singularly unsuccessful, indicating that the beam limitation is elsewhere.

Unfortunately synchro-cyclotrons operating at 10 kV cannot effectively use efficient slit-type ion sources. Raising the voltage to 30 or 40 kV would allow slits to be used, greatly increase the useful beam, and cut out most of the unwanted ions that produce the space charge. If anything like a V^3 dependence still applies under these conditions, a figure of 100 μA is very conservative.

A conceptual design is shown in Fig. 2. The field is assumed to be less than isochronous and the shimming effort is confined to removing harmonics and producing a

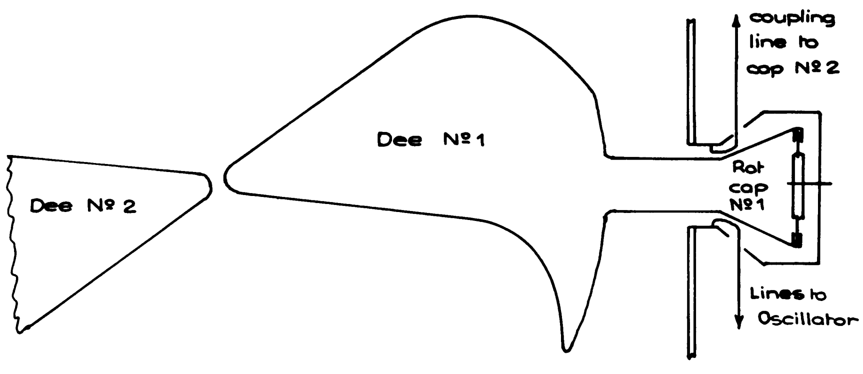

Fig. 2 Conceptual design of a low-range, high-voltage FM system for a sector-field cyclotron.

smooth variation with radius. Two symmetrically placed dees are used to remove the first harmonic and double the gain/turn. A self excited oscillator is envisaged which would drive one of the dees, with power fed to the other dee through a full-wave line, of non-uniform Z_0, which would also serve to lock the two resonant systems together.

The reduced FM range is achieved by eliminating the high frequency portion. This is most important. Every cyclotron RF designer knows that attaining the upper limit is difficult in large structures. But in the design of the FM portion, the advantages of reduced range are partically offset by the higher voltage and repetition rate required. Vibrating blades seem quite unpromising. If rotating capacitors are used, they can have larger spacings and fewer teeth per row, but they must have more, or run at a higher speed. In the conceptual design of Fig. 2 the systems must be synchronized by using servo control which is now quite accurate, and probably ferrite trimming. If the FM range is small enough the all-ferrite system is very attractive. Insulators, placed as shown in Fig. 3, make it possible to locate the ferrite in air.

Fig. 2 and 3 apply to a magnet similar in size and geometry to the isochronous machine, but the general concept applies to any frequency modulated cyclotron. Even a small amount of ridging and some reduction in frequency range, sufficient to permit the use of a slit-type ion source with accelerating electrodes, should produce a sizable increase in beam.

The Negative Hydrogen Ion Cyclotron

Because of the large spiral angle required for an efficient H^- magnet designed for 700 MeV[4], no possibility exists for using dees in the valleys. The minimum gap must be increased, and the most direct and simple approach appears to be the forshortened $\lambda/4$ sheet transmission line, operating on the third harmonic at approximately 11 Mc/s.

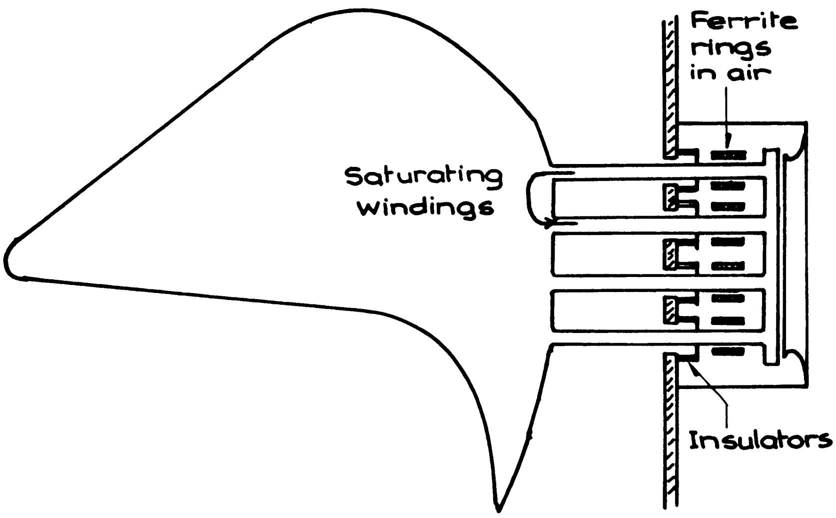

Fig. 3 Conceptual design of a ferrite FM system for a sector-field cyclotron.

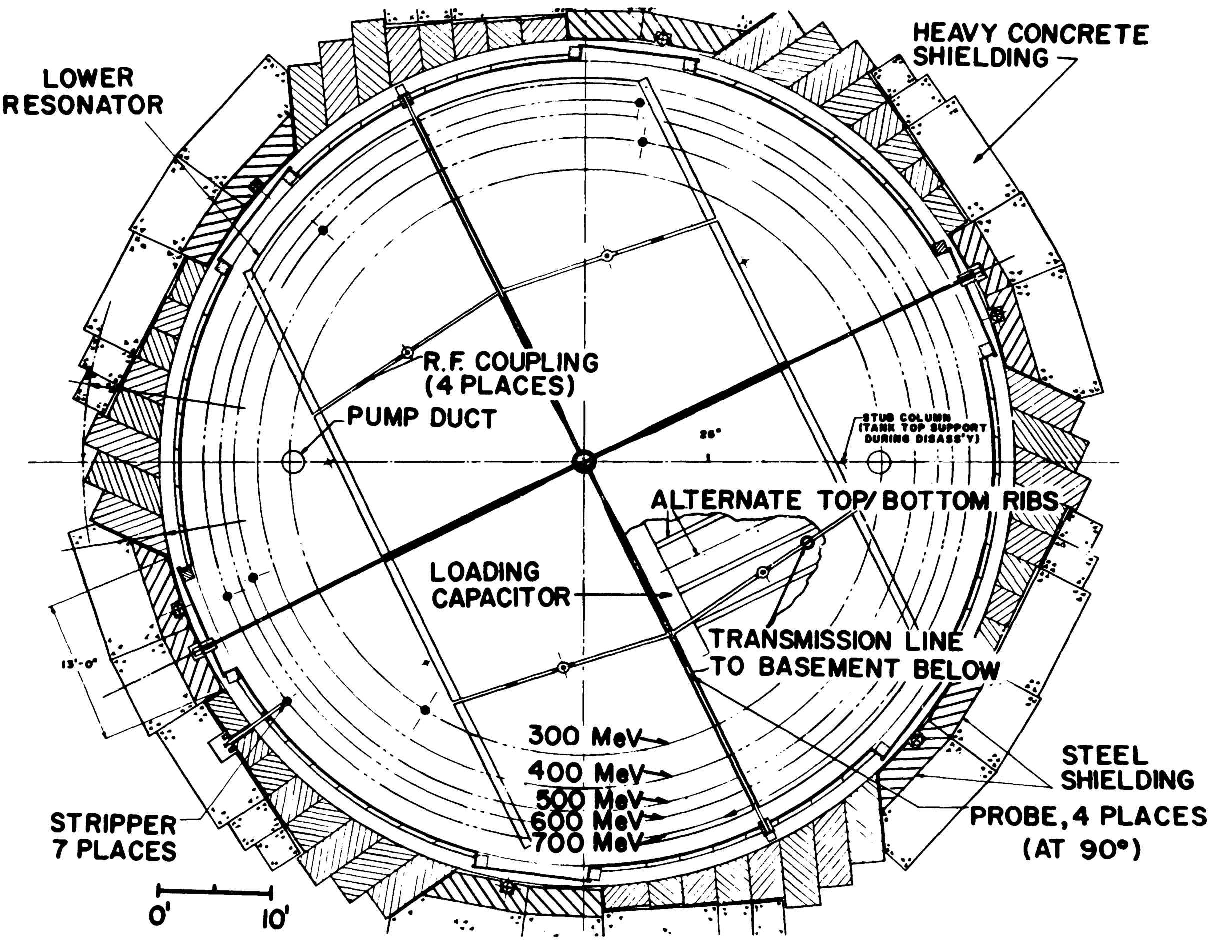

Fig. 4 Sheet transmission line RF system and drive coupling method for a negative-ion cyclotron.

This is a very simple RF system; the only interesting feature is its size (about 20 by 66 ft for each dee), see Fig. 4 and 5. For convenience in handling and construction, the two dees are shown in the form of 16 separate resonators, consisting of 8 similar inner units and 8 similar outer units. The upper units are so tightly coupled to the lower units, both magnetically and electrostatically, that it is quite feasible to feed power from the bottom side only. There are four symmetrical drive points as shown in Fig. 4, and, as in the first study, four beam-type tubes are envisaged as the final amplifiers.

With such tight coupling it appeared that relative mechanical deflections between adjacent units would cause very small unbalance voltages. A 1/5 scale model of a small portion of the dee was built to test this feature and showed a 2% difference for a 1 in. relative displacement of adjacent dee lips (3% of the magnet gap). Such insensitivity could well eliminate the need for remote tuning. The model and generator were of the same type as used in the first study, and showed a power input requirement of 600 kW for 100 kV at each dee lip, in good agreement with a calculated value of

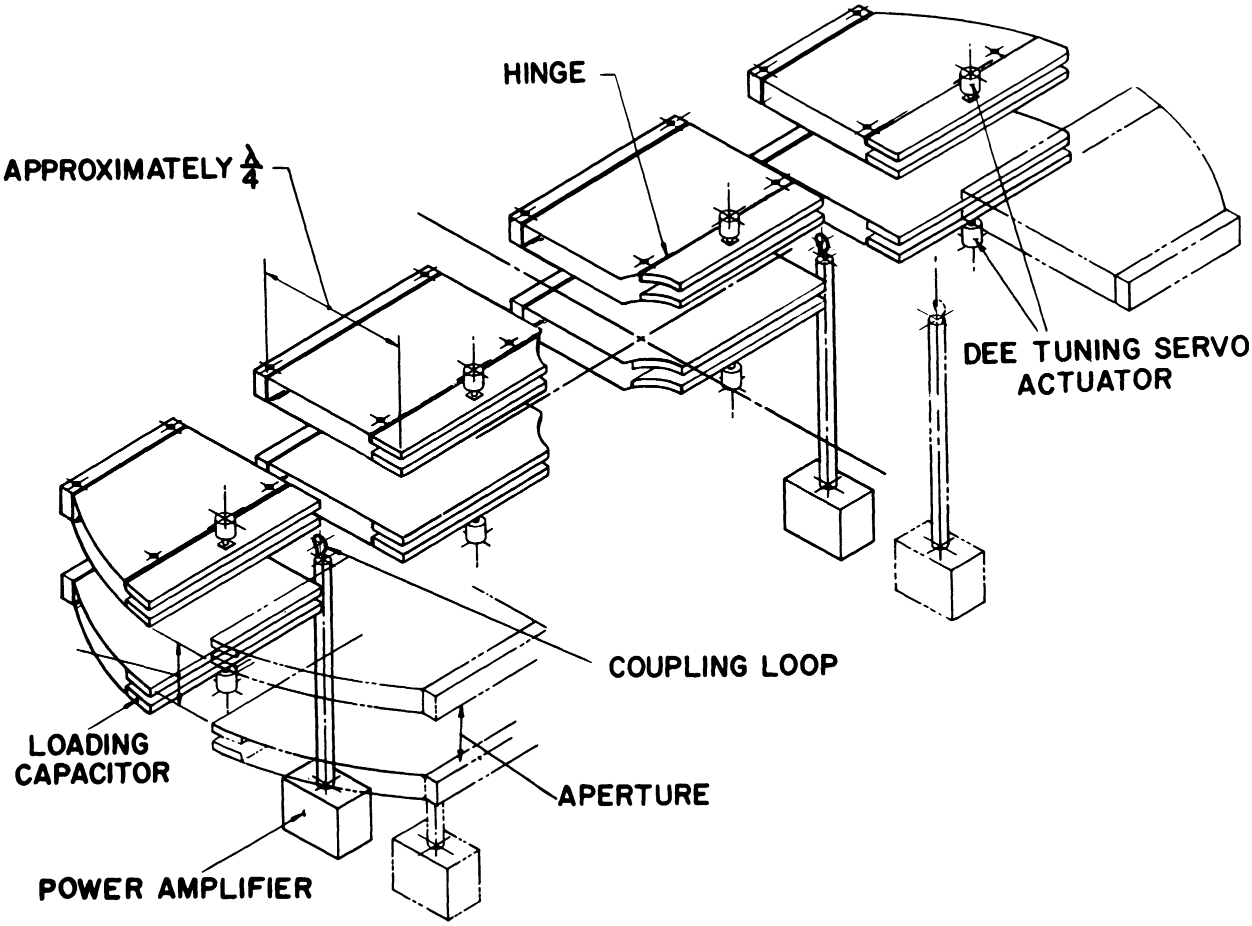

Fig. 5 Exploded view of individual sheet transmission line resonators for a negative-ion cyclotron.

500 kW. The effect of adding cantilever beams to both dee and liner to eliminate all other means of support was not modelled. It is estimated that, neglecting beam loading, this effective decrease in gap will roughly double the power (which varies as $1/(\text{gap})^2$).

References

1. D.J. Clark et al., Nucl. Instr. and Meth. 18-19, 1-25 (1962).
2. J. Sanada et al., Proceedings of the International Conference on High Energy Accelerators, Brookhaven, 1961.
3. L. Henrich et al., Rev. Sci. Instr. 20, 887 (1949).
4. J.R. Richardson, AEC Report No P53, (1962).

DISCUSSION

WATERTON : Are any current limitations introduced by space charge build-up due to non-uniform distribution of the accelerated orbits at various instants during the frequency modulated cycle?

MACKENZIE : No, the space-charge limitation, once the ions are in the region of magnetic focusing, is a negligible factor. The vertical repulsive forces are constant in the region of magnetic focusing; in the central region they become very serious if accelerating slits are not used.

WATERTON : You are referring to mean currents of one milliampere or so?

MACKENZIE : Yes.