The R-F System for the University of Colorado 52-Inch Cyclotron

W. R. Smythe

The University of Colorado cyclotron was conceived as a variable-energy, isochronous machine which would cover the energy region immediately above the electrostatic accelerators.

Figure 161 shows the requirements that this imposes on the r-f system. The upper limit of the curves is determined by the maximum Bρ of the magnet. With a maximum Bρ of 7.8 kilogauss-meters, the cyclotron can produce 30-Mev protons and alphas, 15-Mev deuterons, and 40-Mev helium-3 nuclei.

The full energy range capabilities of the cyclotron magnet may be realized with a 3:1 r-f tuning range. An r-f system which will tune from 21 to 7 Mc/s will cover these angular frequencies; particles with lower angular frequencies may be accelerated by harmonic operation. For example, a particle with an angular frequency of 6 Mc/s can be accelerated by tuning the r-f system to 18 Mc/s and allowing the particle to spend three half cycles inside of the dee instead of one.

After the frequency range of the r-f system is determined, then the electrode configuration and electrode voltage must be selected to give an appropriate voltage gain per turn. Some factors involved are the tolerance for magnetic field errors, access to the beam region (for extraction, probes, etc.), and the desire to restrict the power input to a reasonable value. In a variable-energy machine, it is desirable to have a high voltage gain per turn so that a change in beam energy will not necessitate an excessive amount of magnetic field trimming. Another consideration is the symmetry of the dee-gap voltage. On the usual two-dee machine, there is less voltage across the gap on the side toward the dee stems than there is on the other side. Our decision was to obtain a maximum energy gain of 150 kv/turn by use of a single 180° dee and a dee voltage of 75 kilovolts.

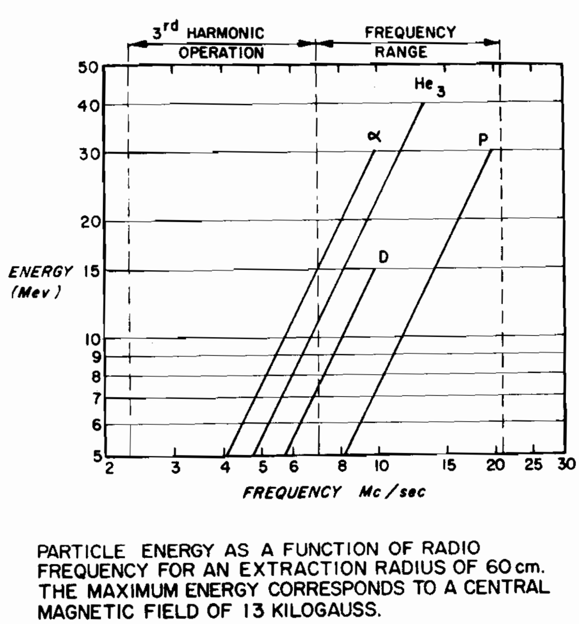

Fig. 161. Proton, deuteron, helium-3, and alpha-particle energy as a function of the angular velocity of these particles at an extraction radius of 60 centimeters.

Figure 162 shows the geometry of the r-f system that we have chosen. We considered a variety of schemes, such as were talked about this morning, and ended up with what is probably the oldest cyclotron resonant circuit. We have a single dee with a 10-in. stem inside a 40-in. tank. The internal dee aperture is 1.5 in., the external dee height is 2 in., the dee-to-liner clearance is 1.2 in., and the diameter of the dee is 51 inches. The dee stem is

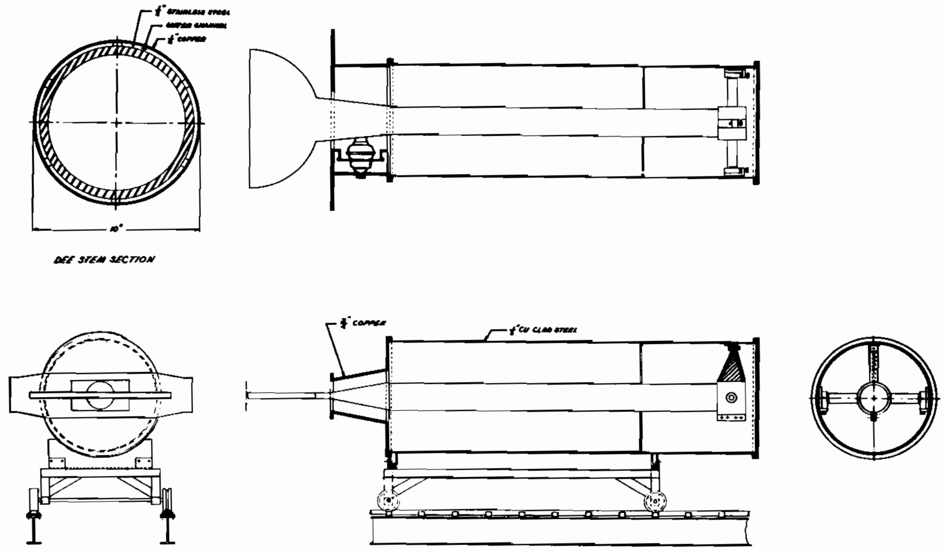

Fig. 162. The dee, dee stem, and dee-stem tank, shown rolled back from the cyclotron. Not shown is the r-f power amplifier which will be mounted on the side of the tank.

cantilevered from a three-point support so that the end plate of the tank can easily be removed for access. The movable short is very schematic because that is the way it is in our minds. [Laughter]

The main structural member of the dee stem is a 9.25-in. OD stainless steel tube with a 1/2-in. thick wall. Coaxial with this tube is a 1/8-in. wall, 10-in. OD copper tube which carries the r-f current. Cooling water is circulated in the 1/4-in. space between the two tubes. The circular tank whose inner surface carries the r-f current is made from copperclad 1/2-in. steel. The transition tank between the circular tank and the acceleration chamber is fabricated from 3/4-in. copper. The entire assembly is mounted on rails so that it may be rolled back from the cyclotron for maintenance. Not shown in the figure is a 10-in. diffusion pump at the back of the tank.

In the transition section we have shown a variable vacuum capacitor. This is something that we are not convinced will work satisfactorily, but we feel that it is worth trying. With a vacuum capacitor, the cyclotron energy can be varied 10 to 20% without moving the short circuit. If the vacuum capacitor fails due to sparking, we will build our own capacitor in the same space; however, we will then be restricted to a much smaller frequency variation.

The short circuit travel leaves little room for a coupling loop in the tank. The problem of coupling inductively is further complicated by the fact that the inductance of the resonant circuit varies by a factor of ten. For these reasons, we have decided to drive the system by capacity coupling to the dee. The coupling can be varied easily by moving the capacity coupling probe in or out. I was quite pleased this morning to learn that the Russians are using capacity coupling in a synchrocyclotron.

Figure 163 is a block diagram of the power amplifier. In addition to the blocks shown on the diagram, there will be a phase detector which will compare the phase

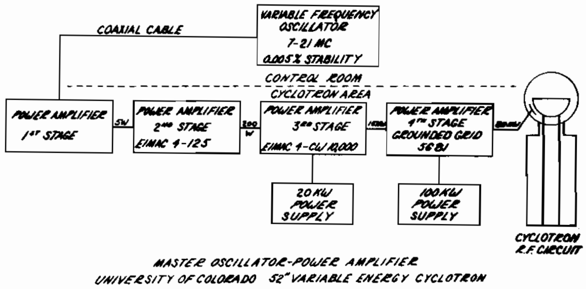

Fig. 163. Block diagram of the r-f system.

of the r-f flux of the resonant circuit with the phase of the driving voltage. The output of the phase detector will operate a compensating capacitor to keep the resonant circuit tuned to the driving frequency. In addition, there will be a feedback loop to stabilize the dee voltage. At present, the first two stages of the power amplifier are built, and the third stage is under construction.

The full-scale model of the r-f circuit tunes from somewhat below 7 to 26 Mc/s; however, the power requirement and the current density make operation at full voltage above 21 Mc/s undesirable. In addition to information on tuning characteristics, the model has been used to verify estimates of the power required to obtain a dee voltage of 75 kilovolts.

Figure 164 illustrates the first of the two methods employed to measure the power requirements. The cyclotron resonant circuit has been represented by a lumped parameter circuit with the shunt resistance R_{SH} representing the losses of the system. A measurement of the shunt resistance of the circuit will then allow a calculation of the power dissipated with a dee voltage of 75 kilovolts. The measurement consists of comparing the shunt resistance directly to a known resistance R. The constant current excitation is obtained by weakly coupling the model to a loop driven by a signal generator at constant voltage. If the coupling is purely inductive and sufficiently weak, it can be shown to be equivalent to constant current excitation.

The second method directly measured the dee voltage produced for a given power input. A 304 TL tube was used in a tuned-grid tuned-plate circuit with the model serving as the plate circuit. The plate dissipation of the 304 TL was determined by use of an optical pyrometer and a previously prepared calibration curve. The entire plate input power less the plate dissipation was assumed to be the r-f input power to the model. That this assumption was not always valid is shown by the fact that the plate choke went up in smoke on one occasion, and generally ran hotter than it should have.

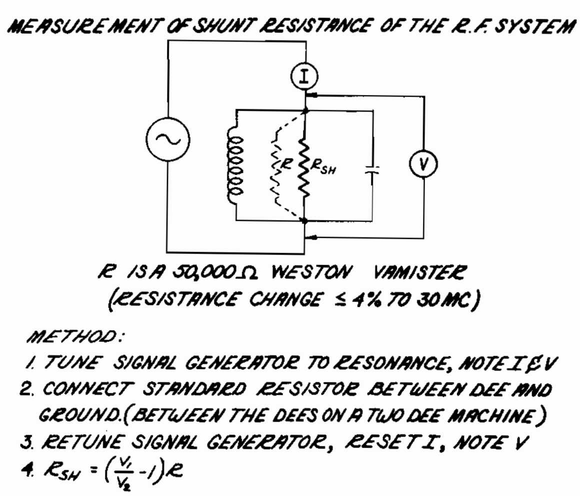

Fig. 164. A method of directly measuring the shunt resistance of a resonant circuit.

The results of these measurements are shown in Figure 165, which also indicates the tuning range of the model. Figure 165 shows that the maximum frequency needed for first harmonic operation is 19.8 Mc/s; so the maximum r-f power required, exclusive of beam losses, is 50 kilowatts. The splatter of the points obtained by the power oscillator method above 18 Mc/s is believed to be associated with the excessive power dissipation in the plate choke. Aside from this difficulty,

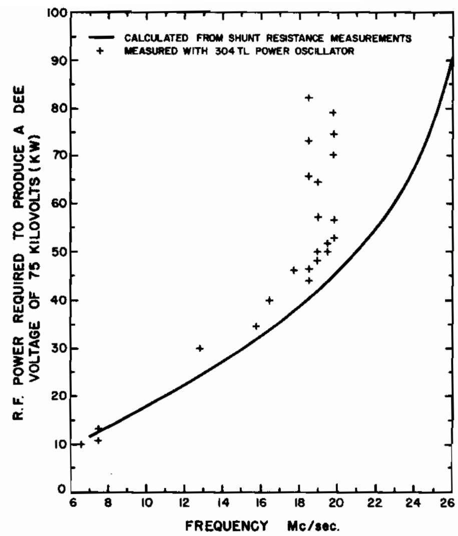

Fig. 165. Experimental results obtained with the full-scale model of the resonant circuit model.

the agreement between the two methods is satisfactory.

In conclusion, I would say that the present system seems satisfactory. However, we still have some problems to solve, such as the short circuit design, the transmission line from the last stage of our power amplifier to the coupling capacitor, and the gang tuning of the power amplifier.

CHAIRMAN RICHARDSON: I would like to remark that this is actually not the oldest r-f system. The oldest system you know had two dees. It was really a lump parameter system, and it had a coil and you tuned it by taking the coil and squeezing it.

GREEN: The coil was an automatic gas line wound around a battery, as I recall. [Laughter]

SCHMIDT: Why are you planning to put the pump behind the spider rather than in front?

SMYTHE: I don't want a hole that I have to move the short over.

SCHMIDT: Is it not possible to place it close enough?

SMYTHE: No. We have a 20-in. pump to take care of the main vacuum chamber and the 10-in. pump is to take care of the tank.

B. H. SMITH: What current do you run on the center conductor?

SMYTHE: It is around 100 amps per inch (rms).

WORSHAM: Do you have to cool the copperclad steel liner from the outside?

SMYTHE: Yes, there will be some cooling, but the heating is not nearly as intense, of course, as it is in the center conductor.

WORSHAM: One of our mechanical engineers brought up problems in soldering tubes to copperclad steel. At least in our case, it was copperclad stainless. I just wonder if you have gone into these problems.

SMYTHE: In our case, it would not be stainless steel; we have not thought about it one way or another.

GREEN: We have in a whole bunch of Linac tanks made to very close mechanical tolerances and had no trouble at all.