The R-F System of the Variable-Energy Cyclotron at the University of Rochester

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I want to talk about the r-f system of the 26-in. cyclotron, butffirst let me say a few words about the history of the machine. The original cyclotron built around the 26-in. magnet was one of the earlier cyclotrons. It was put in service in 1935. It had the customary two dees, supported by dee-stem insulators, and its tank-circuit inductance was provided by an external "hairpin" of copper tubing. The frequency of the oscillator could be changed only with difficulty. In 1953 the cyclotron was still being used for research work, but it was apparent that some changes had to be made, partly to make the machine more suitable for modern low-energy nuclear research and partly because of the practical necessity of repairing it and of providing adequate shielding.

Those of us interested in making the change were physicists who had one goal in mind, we wanted to do experiments with an external beam. So we looked for a design which would be satisfactory for our purposes for some years to come. We decided to make the machine variable in energy, to provide an adequate shielding arrangement, and to provide a beam handling system with good energy resolution, see Figure 168. The rebuilding was completed in 1954*. Since then a number of minor changes have improved operating conditions considerably. I understand that Dr. Alford will describe the operation of the machine tomorrow.

Figure 169 shows the inside of the dee chamber. There is a single dee attached to the dee stem which screws so that it is easily removable. There is an electrostatic deflector. The beam passes through an iron pipe channel after being deflected.

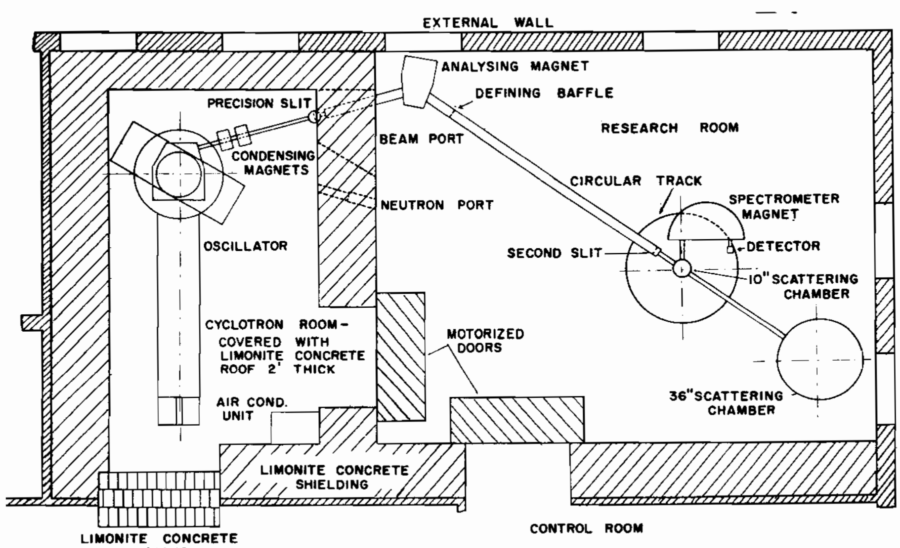

Fig. 168. The variable-energy cyclotron installation at the University of Rochester.

*Fulbright, Bromley, Bruner, Hamann and Hawrylak. Preliminary Report on the New 8-Mev Variable-Energy Cyclotron of the University of Rochester, NYO-6541 (1954).

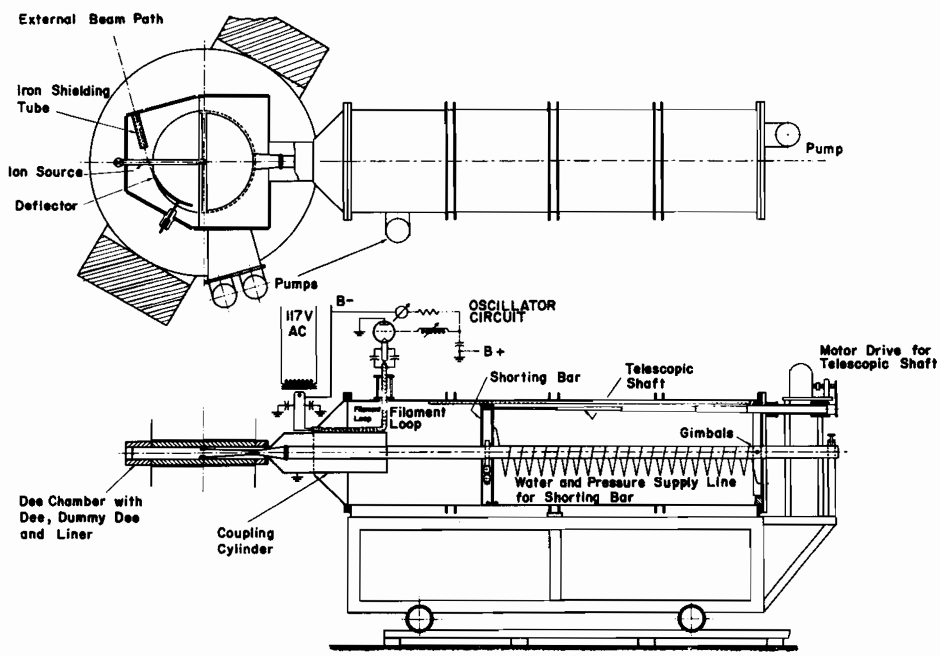

Fig. 169. Two views of the Rochester cyclotron, showing the r-f system and various mechanical features. The pole diameter is 26.4 inches. The main dee-stem tank is a piece of seamless copper pipe 26 3/8-in. OD, 114 in. long, with 1/8-in. wall. The coupling cylinder is 10 in. in diameter. The shorting bar has an excursion of about 82 inches. The dee stem is 3 in. in diameter.

Figure 169 also shows the machine in section. The basic geometry of the dee tank circuit is the usual coaxial one with a shorting bar. The one exceptional feature is a re-entrant cylinder to help provide tight coupling to the oscillator tube, which is placed as far forward as possible. The shorting bar can be moved back and forth by remote control. It moves on an internal cog-railway system, driven by an external motor which drives a telescoping splined shaft, which in turn drives cogs mounted on the shorting bar.

The form of the r-f cavity was selected after careful study of several 1/4-scale models of different types of oscillators. This type proved the most stable and the least susceptible to parasitic modes of oscillation. Because of electro-mechanical difficulties with the grid coupling loop and because of multipactor difficulties, the oscillator was later modified*. Figure 170 shows the oscillator in its original form. It is essentially a tuned-plate tuned-grid oscillator. A single cathode loop of copper tubing couples the 5771 oscillator tube to the cavity. Filament current is provided through two welding cables slipped through the cathode loop. The grid tank coil, externally mounted, is tuned by means of a remotely controlled motor. The adjustment of the grid loop turns out not to be critical.

*Petrovich, M., Preskitt, C. A., and Hamann, A. Modifications of the Oscillator of the Rochester 27-Inch Variable-Energy Cyclotron, NYO-7816 (1956).

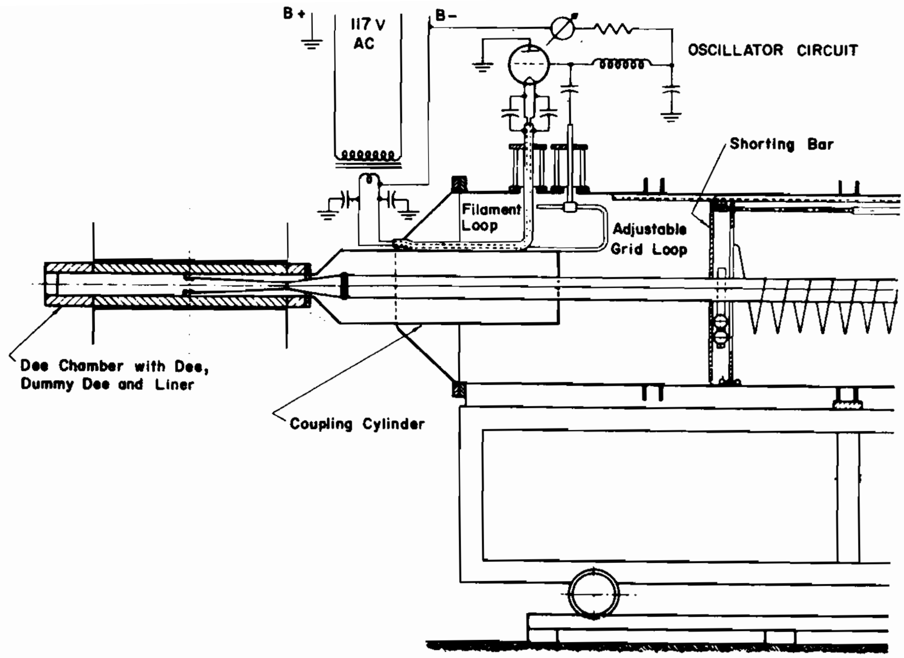

Fig. 170. The oscillator in its original form. The adjustable grid loop proved unsatisfactory in design and the oscillator was hard to start because of the multipactor effect, so the grid loop was removed and the oscillator tube was connected as shown in Fig.

To change the energy of the beam the operator must change both the strength of the magnetic field and the frequency of the oscillator. To change the frequency he first pushes a button to unclamp the bar, pushes a second button to move the bar to the desired new position (which previously he has read from a plot of position vs energy), and then he presses another button to clamp the bar in its new position. In some cases the operator must also change the grid loop. This is also done by pushing buttons. The positions of the bar and the grid loop are indicated on the control desk by Veeder-Root counters. A safety circuit is provided to prevent power from being applied to the oscillator when the shorting bar is not clamped.

The multipactoring problem has not quite been eliminated. In its present form the oscillator usually starts on the first push of the starting button, but under some conditions requires several tries. On rare occasions, which occur most frequently when the machine has been shut down for a while and when the shorting bar is at or near the lowest frequency position, there is sufficient trouble so that the following special procedure is followed. The dee is lowered by use of a hydraulic mechanism attached at the outer end of the dee stem until it nearly touches the bottom of the dee chamber. This is done by operating push buttons on the control desk. The oscillator then can be started, after which the dee is raised again. After the oscillator has been run for ten or fifteen minutes no further trouble is ordinarily encountered. These difficulties are not very serious, so no one has yet bothered to devise a solution.

The shorting bar is shown in Figure 171. Its main body is a copper disk 25 in. in diameter and 3/8 in. thick. The dee stem, a 3-in. OD silver-plated stainless-steel tube with a 1/4-in. thick wall, passes through a 5-in. hole in the center of the copper disk. Silver strips, 1/64-in. thick, are screwed at one end to the disk around

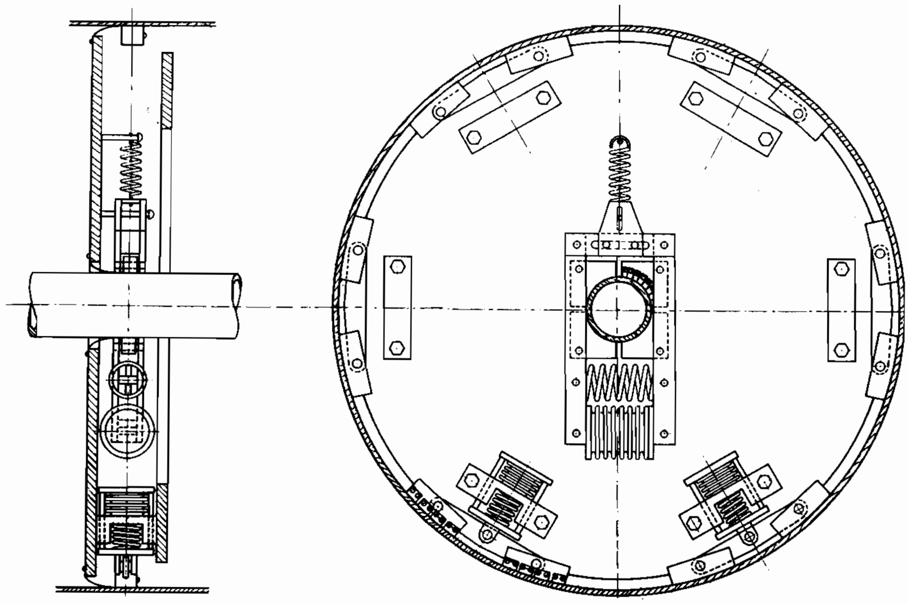

Fig. 171. Schematic view of the shorting bar showing typical clamping springs and metal bellows.

the circumference of the hole and at the other end to four copper quadrants mounted loosely on a steel framework. A powerful steel spring normally pulls the framework together so that a connection is made between each of the silver strips and the outside of the dee stem. Actually the silver strips do not touch the stem. A piece of copper loom (braided fine copper wire) is mounted on each quadrant covering the silver strips and acting as an electrical and mechanical cushion. These cushions proved necessary to avoid burning out the silver strips. A metal bellows is provided so that the clamp can be released pneumatically. The whole central clamping unit is partially supported by a spring attached to the main disk.

Around the edges of the disk are more silver strips which are normally pressed against the inner surface of the outer conductor by twelve blocks arranged in six units. The force is supplied by six coil springs. Six metal bellows are provided to permit pneumatic unclamping. A common copper tubing line connects all seven bellows together and is connected to a solenoid-operated valve outside the vacuum system. By pressing a button the operator lets air in and causes the entire clamping system to relax at once.

All of the iron pieces are, of course, mounted on the back side of the shorting bar disk, away from the oscillator. These pieces include ball bearings, springs, gears, a bicycle chain linking the three cogs of the internal railway system, etc. There has been no evidence of overheating of these parts, except when the silver strips around the dee stem burned out (before the braided copper cushions were added).

Water cooling is applied to the main disk and to the four stem-clamping quadrants. The water enters and leaves the vacuum tank through 1/4-in. copper tubes, wound in the form of a loose helix together with a similar pneumatic pressure line (for unclamping), and enclosed in a shield of copper braid. The whole is supported by the back part of the dee stem.

The cooling water for the dee and stem enters through long pipes lying inside the stem and returns through the main body of the stem. It was necessary to provide a set of tangentially bored holes along one of the input tubes so that the water in the main body of the pipe rotated about the axis of the pipe, otherwise differential heating produced a serious downward deflection of the dee when the oscillator was turned on.

The oscillator has a frequency range of 10 to 22 Mc/s. Its efficiency has been determined to be greater than 60%. The Q of the resonant circuit varies from about 800 to 1600 over the whole tuning range. Power inputs up to 40 kw are used. The dee voltage is about 40 kv. The frequency stability is excellent. In short the oscillator should receive very good marks on each of Dr. Richardson's items, except for ease of starting, where a grade of C is about right.

One last item: the linear current density where the shorting bar clamps the stem is somewhere between 70 and 100 amp/in.

B. H. SMITH: Is that maximum, or rms current?

FULBRIGHT: Rms. This is a high current density, but the system holds up, even though the silver plating on the stem is somewhat rough. Of course, we would have preferred to use a stem larger in diameter to simplify electrical and mechanical problems, but were unable to do so because of the limited amount of space available in the cyclotron room, which forced us to provide a large amount of inductance per unit length of line.

LIVINGSTON: Did you mention what the dee voltage was?

FULBRIGHT: We have not really measured it, but from the known Q, dee capacitance, and power input we judge that it is about 40 kv.

LIVINGSTON: And would you repeat the frequency range?

FULBRIGHT: Ten to 22 Mc/s. We use a peak magnetic field of about 15,000 gauss, and we should be able to get out 8-Mev protons, but in fact we are limited by oscillator power input. The highest energy deflected beam of protons with which any measurements have been made is 7.5 Mev. Extensive measurements have been made at 7.25 Mev. This machine accelerates deuterons to 4.2 Mev.

SMYTHE: Are the silver fingers pure silver or silver alloy?

FULBRIGHT: Pure silver.

SMYTHE: What percentage of contact do you have around the outer cylinder?

FULBRIGHT: Approximately 50%.