Central Orbits in the Cyclotron

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The calculations that I will speak of are very simple calculations of the orbits in the vicinity of the ion source, made in order to get some idea of the volume in phase space that would be injected into the A-G field of the machine. They were done mainly by S. C. Miller, Jr., of our group. We modeled the ion source and puller for the system we expected to use, and we made our calculations from the fields obtained from the model.

Figure 64 shows a schematic of the arrangement. There is a single dee with a grounded dummy dee; the ion source and slotted puller electrode are similar to those used elsewhere. The dimensions of dee, dee to linear gap, ion source and puller are approximately the final design values. Figure 65 shows a plot of the median-plane potential distribution. We also investigated the field configuration when the puller was placed at an angle of 30° to that shown in Figure 64 to see what effect turning the puller would have on the acceptance phase angle for the machine. From these distributions, we developed analytical formulas which gave the potential at all points in the median plane to about 3 percent. The general potential was expanded to terms in Z^4 for purposes of calculating the field components for the orbit calculations. Orbital and axial motions for a maximum of five turns were calculated; at that point, the trajectories would have passed into the A/B field region of the machine.

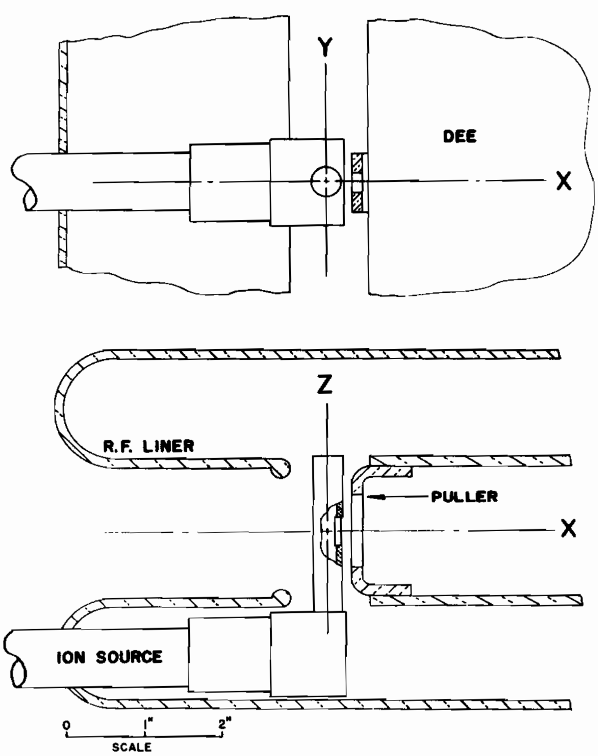

Fig. 64. Schematic arrangement of the dee liner and ion source configuration.

Figure 66 shows the orbital motion for protons. The field conditions are as follows:

$$B_o = 12.8 \text{ kilogauss}$$
$$f_o = 19.6 \text{ Mc/s (protons)}$$
$$\lambda\!\!\!^{-} = 2.43 \text{ meters}$$
$$V_o = 7.5 \times 10^4 \text{ volts}$$
$$\frac{eV_o}{mc^2} = 8.01 \times 10^{-5}$$

A uniform magnetic field is assumed and the electrical and orbital frequencies were set equal. These results are not very different from those developed, for example, by W. B. Powell and are quite familiar. There is a considerable shift in the orbit center with the acceptance phase; one set of points corresponds to 0° and the other to 30° phase. Figure 67 shows the corresponding axial motion. The injection phase, ϕ_o, is the phase at which the particle is started relative to the maximum of the r-f potential. Thus, it is seen that particles injected ahead of the r-f maximum are driven out of the machine within a few turns. Only particles injected behind the maximum of the r-f

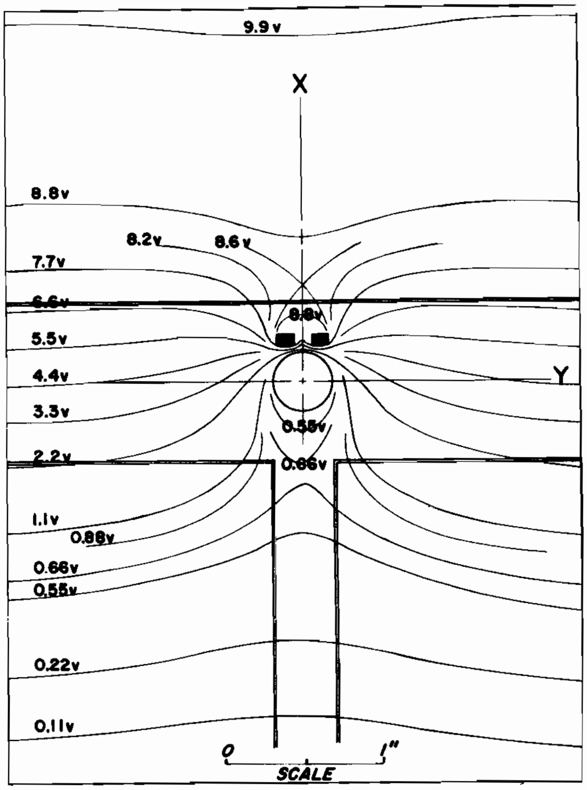

Fig. 65. Electrolytic tank measurements of the median-plane potential distribution. Dee to ground potential was set at 10 volts. Note that for all computations the ion source and puller were moved 0.5 cm toward the dummy dee to center the orbits.

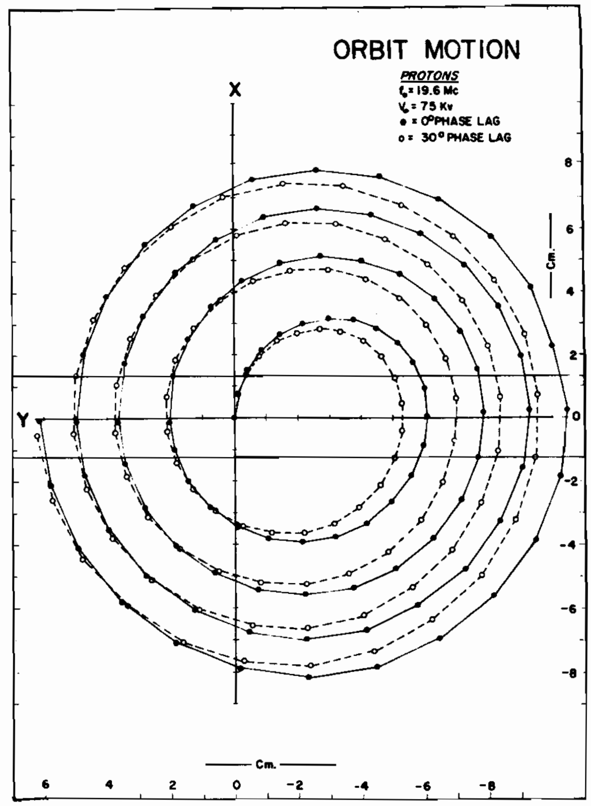

Fig. 66. Orbit motion for protons.

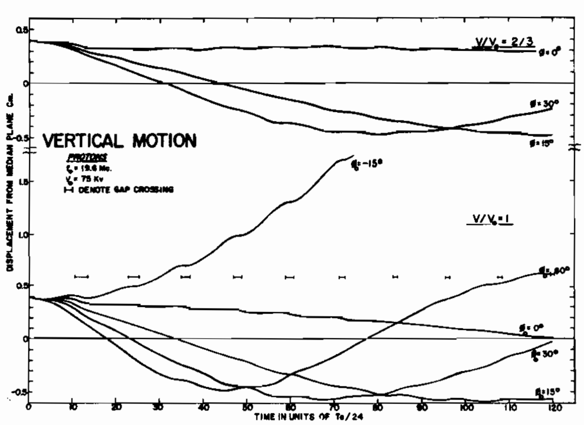

Fig. 67. Axial motion for protons. The time is in units of Te/24 where Te is the r-f period. The upper set of curves were made for 50-kv dee voltage.

voltage will be accelerated. One probably would not accept particles outside the phase range of 0 to 15°.

Another set of runs was made with the dee voltage set at 50 kv. The axial electrostatic focusing depends only on the number of turns and the phase angle at which the particle crosses the gap. Thus, for particles starting 4 mm above the median plane, it is possible to estimate the injection conditions into the A-G field region. We now have numbers which represent a rough approximation to the radial and axial amplitudes and momenta about equilibrium orbits for use in calculation of the amplitudes to be expected during the complete acceleration cycle. The center of the orbit will be displaced about 1 cm parallel to the edge of the dee for a change in the injection phase from 0 to 30 degrees.

The calculations also gave us some idea of what the phase bunching during the first few turns in the machine would be. Contrary to the results from other calculations that one would get fairly large phase bunching in the first few turns, we found that there was not more than 10^{o} of phase bunching or, to put it another way, an ion injected with a 30^{o} phase lag will have, after five turns, a phase lag of about 20 degrees. The spread in injection phases is bunched about 30 percent. The strong phase bunching which has been noted during the first few turns occurs only when a puller electrode is not used.

From these results, we have also estimated the contribution to the focusing from the electric forces. The result is that in our machine at the extraction radius, they contribute about 1% of the corresponding magnetic focusing and vary inversely as r^2, or inversely as N^2. At the center, the electric forces represent the only focusing. It is also possible to determine where to place slits to define the beam accurately and accept particles with prescribed injection phases. They can be placed behind the dummy dee in the field free region or on the edge of the dee. A number of problems on the best location for optimum beam definition remain. It is quite probable, however, that for efficient extraction, the orbits must be programmed from the center for all final beam energies. The results are available in more complete form*

CHAIRMAN JUDD: Thank you. I must confess that when we began this morning I was unaware that Professor Thomas was in the audience. I have asked him to say something; he indicated that he might like to make some comments about the computational side of the subject. Professor Thomas.

*S. C. Miller, Jr., and D. A. Lind. The Problem of Central Orbits for Fixed Frequency Cyclotrons. 1959, University of Colorado.