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Operation of the Los Alamos Variable-Energy Cyclotron

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The Los Alamos Variable Energy Cyclotron constitutes a development intermediate between the ordinary low energy cyclotron and the medium energy isochronous machines discussed in this conference. Since it does incorporate a number of the features common to isochronous machines and it has been in operation for several years it seems pertinent to discuss its design and the relevant operating experience obtained with it.

This cyclotron was designed to use the magnet structure of the old Harvard 42-in. cyclotron. It has a flutter field with 3-fold azimuthal symmetry, although it is not isochronous, and it accelerates a variety of particles over a range of energies as listed in the table below.

Particle	Energy Range (Mev)	Internal Beam (ma)	External Beam (μa)
Protons	3 - 9	5	120
Deuterons	6 - 15	2.5	100
He^3	12 - 26	2	100
He^4	12 - 30	2	100

To obtain this range of energies it is necessary to vary the average magnetic field from about 18 to 5 kilogauss and to vary the frequency of the dee excitation from 8.3 to 13.8 Mc/s. The r-f system was discussed in an earlier session; the magnetic field problems and ion optics will be discussed in this session. A 3-fold flutter field of $\pm 5\%$ is established by varying the magnet gap, as shown in Figure 259. At the time the iron circuit was designed it was believed that the magnet gaps could not be decreased sufficiently to permit enough flutter to give positive axial focusing for the isochronous condition without severe loss of beam intensity. The flutter field was added in the belief that it would improve the stability of the magnetic median surface, as well as improve the axial focusing in the central region. While calculations indicate that the gain in axial focusing is marginal, the machines operation indicates there is a large gain in axial stability and in beam intensity.

One of the main problems solved in this machine is that of maintaining a radial distribution of the magnetic field intensity that is independent of saturation effects. This was achieved by the use of an iron ring or Rose shim at the full radius of the poleface and a current coil ring just inside the Rose shim (Fig. 260). For low values of magnetic field the Rose shim over corrects the edge giving rise to a central valley in the magnetic field intensity which can be filled by the current coil. For high values of the magnetic field the Rose shim is insufficient to correct the edge, so the current coil is used to depress the central region to match the edge properly (Fig. 259).

Considerable shift of the center of the beam orbits has been observed as a function of the value of the magnetic field intensity. Part of this was traced to slight tilting of the polefaces and it was reduced by adding additional mechanical

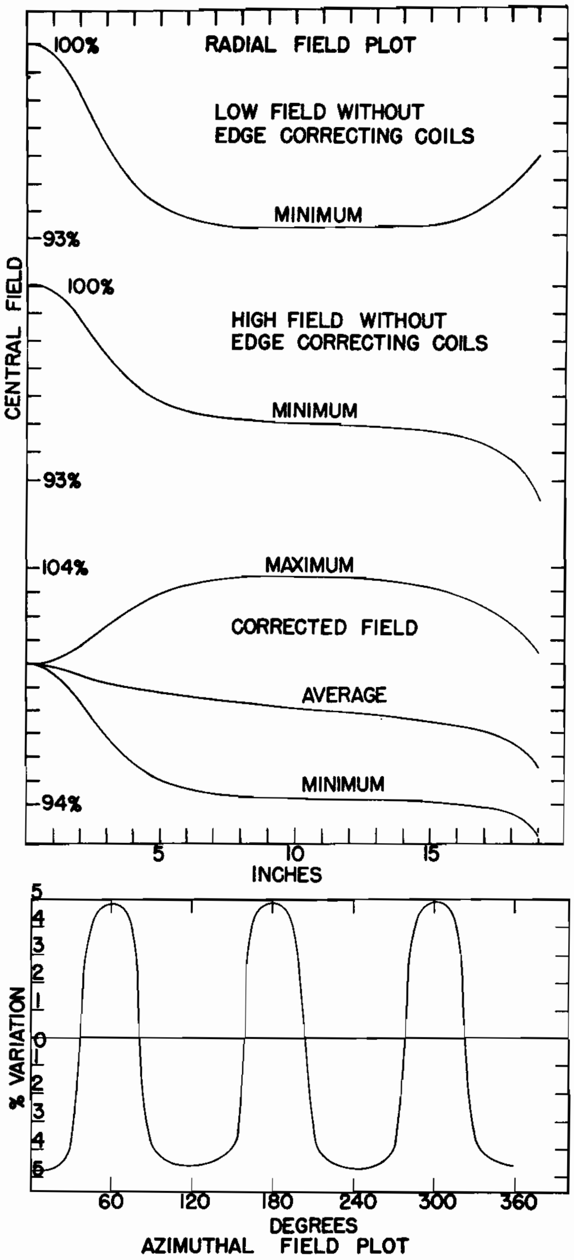

Fig. 259. Magnetic field characteristics.

supports to the polefaces. However, it was apparent that the flutter field decreased the radial stability to such a point that it was found advisable to use a pair of orbit centering coils (Fig. 261). The current in these coils are adjusted empirically to align the beam orbit with the deflection channels. The coils have 900 amp-turns per set and make first harmonic correction to the magnetic field distribution.

The ion source is very similar to the Oak Ridge design except that a curved feeler bar is used and the arc chimney is machined to a matching curve so that there is a strong focusing and extraction field at the ion source. The dees are cut back 20° to give greater access for internal beam experiments and to reduce dee capacity.

In view of the very tight vertical distribution of the beam and the very large beam currents obtained, I believe that it would be possible to redesign this machine to give proton energies in the excess of 30 Mev and make it an isochronous machine by reducing the dee height drastically and making use of the space to add adequate shims.

LIVINGOOD: Are there only two positioning coils, or did the draftsman just forget to draw the others?

BOYER: There are only two pairs. We send the current in either direction to shift the orbit in any direction.

LIVINGOOD: Is the deflector external to the dee, or entirely inside?

BOYER: It is entirely inside. We do have a lot of trouble covering this energy range and keeping the beam in the external channel. There needs to be some adjustment.

SCHMIDT: Have you anything to stabilize the dee voltage?

BOYER: Not yet. There is considerable r-f cycle ripple. A lot of beam modulation arises from this.

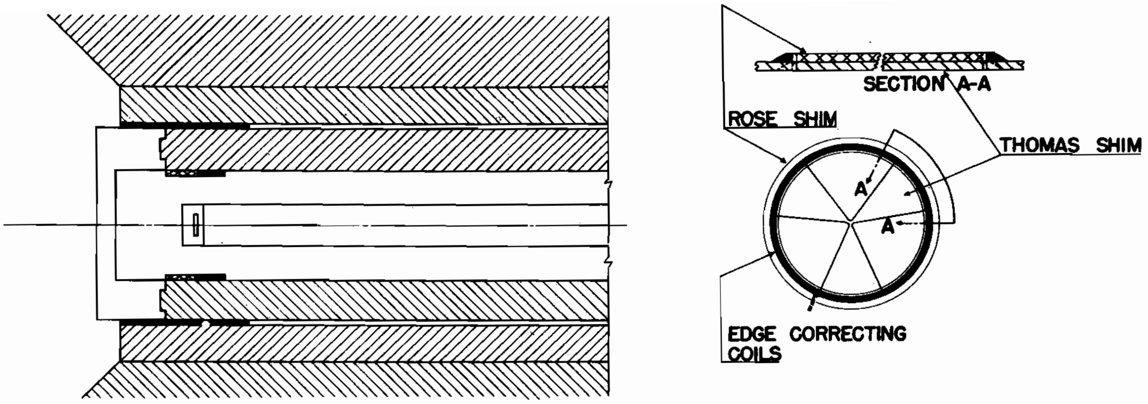

Fig. 260. Magnet and shim geometry.

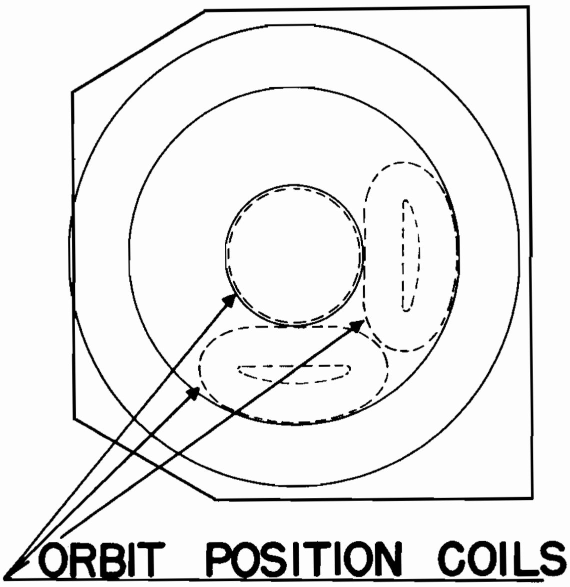

Fig. 261. Orbit positioning coils.

PETERSON: About how long does it take to go from a low-energy to a high-energy external beam?

BOYER: Ordinarily there are enough other different things so that this isn't the limiting factor. Once it was done in ten minutes. But on the other hand, you might well spend a half day or longer, if you want to get the energy right and do some other things.

W. I. B. SMITH: You said you do not shift the median plane. I didn't quite understand, could you enlarge?

BOYER: We haven't been successful in moving the beam up or down. We put a probe in near the center and sent the current through the central coil in one direction and then the other; there is essentially no shift in the position of the beam.

SMITH: This is one coil in one shimming gap?

BOYER: This is one coil in one shimming gap, and we had a maximum of about 1,000 amp-turns. This is something that certainly does not seem to come honestly, according to the theory. There seems to be better stability than one would expect in the median plane, but it is an empirical fact.

SCHMIDT: Can you give any rough guess as to the amount of additional axial focusing over a conventional machine with, say, a 3% field drop? Do you attribute this to having an excess of vertical flutter?

BOYER: It isn't the focusing due to flutter; particularly in that region, since the flutter isn't strong enough. Bob, did you ever get any of those calculations run?

LIVINGSTON: As far as we got, the flutter accounted for about 10% of the focusing, about halfway out.

SCHMIDT: How about all the way out?

BOYER: Apparently, it just is not enough to look very strong, focusing-wise, but it really seems to establish a beam in the center and it is far from clear why it should do that. It may be due to the iron-air interface and the fact that the interface is changing direction.