Beam Extraction in the Livermore Cyclotron

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I hope that the beam extraction experience with our 90-in. old-fashioned type cyclotron will be of some value to you, although your problems with these new sector-focused machines are, of course, quite different.

Let me orient you as to our deflection system with Figure 227, showing schematically the accelerating plane. The deflector system is purely electrostatic. The two sectors are mechanically and electrically independent. With this system we obtained a measure of the angular spread of the beam as it enters the deflector. When we flare out the bottom part of the top deflector, we can get up to 75% of the internal beam through the top half of the deflector, as measured by the beam collected on the bottom half. This flare corresponds to something like a 3^{o} spread. The rest of the deflection system cannot accept and pass such a flaring beam, and typically we run with parallel plates. In this case we get through the bottom deflector normally 15% of the internal beam. If the cyclotron is in a very good mood, we might get 25 percent. Beyond the exit of the electrostatic deflector we get practically all of this beam -- maybe a 10% loss -- though the magnetic channel into our experimental pit maybe 35 ft away.

One feature of this deflection system is the use of the cam-shaped magnet pole-face. Mechanically, you see, it is canted at about 15^{o} to the beam line. However, magnetically it is perpendicular. That is, the beam crosses the magnetic contours perpendicularly so that the focusing effects of this step are neutral, both axially and radially.

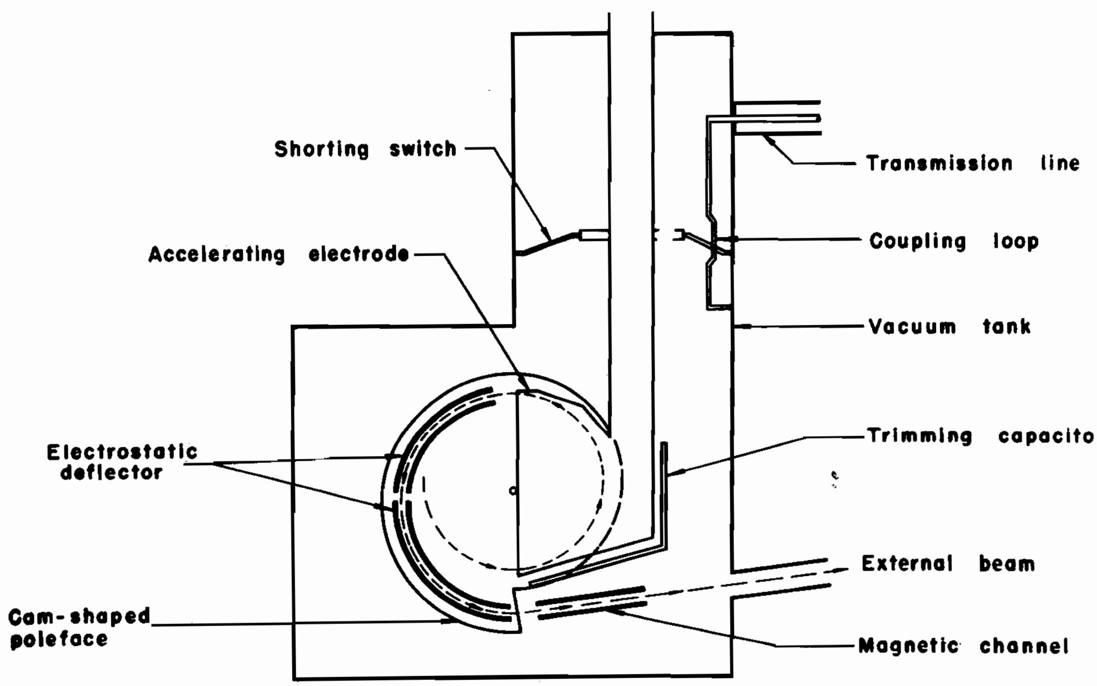

Fig. 227. Schematic drawing of the accelerating plane of the Livermore cyclotron.

You can do tricks with this cam shape. For example, if you have a point source, say for the sake of an example, somewhere near the beginning of the deflector, you can pick this cam magnetic angle such that you can have a focus, both radial and axial, out beyond the cam a few feet. It was tempting to use this focusing property of the cam to control the focal properties of the beam. However, when we were in the design state, we had no idea where the effective point source of the external beam would be, and, in fact, we thought we would have a continuous distribution of effective sources. As it turns out, we do have an effective point source in this external beam, and it happens to be inside the bottom deflector. We made studies of the beam divergence in both the radial and the axial planes. In each case the rays of beam project back to a point inside the bottom deflector. These measurements had an uncertainty on the order of a foot. This position of the effective point source is the same throughout the range of the machine; that is, both deuterons and protons at all energies available in the machine show the same external optics. By the way, the divergence is a little larger in the radial plane ($\sim \pm 0.50^{\circ}$) than in the axial plane ($\sim \pm 0.250^{\circ}$).

The magnetic pipe or channel leading out from the cam has been very useful. Without it, of course, we would get flaring because the magnetic field does not automatically crop to zero immediately beyond the cam. With the iron channel in place the field drops to zero, effectively within a few inches. By making the channel movable along its axis, we can use it as a steering device in the radial plane. If we move it an inch, that will change the beam angle by about a degree.

Incidentally, I should point out that the radial fall-off of our magnetic field continues throughout this deflector region, with the same slope as in the accelerating region, so that n is of the order of 0.01 everywhere here, and the n = 0.2 point is of no concern.

Another thing in the deflection system that we have found useful is the array of poleface windings. We have them arranged on the poleface in quadrants, so that we can put in first and, if we want, second harmonics in the magnetic field. We use these current-carrying coils to make the beam walk in any direction we want. These are used both for aiming the beam into the deflector and for increasing the radial gain per turn as the beam approaches the deflector. Numerically our ΔR/ turn due to the poleface windings is of the order of 0.1 in./turn while out ΔR/turn due to the rf is typically 1/4 in./turn.

Just as an aside, we can use the poleface windings not only for helping in extraction in this manner by giving a ΔR per turn, but we can also change the energy of our machine without changing either the magnetic field or the frequency by shoving the platter around and thus changing the radius of curvature when it enters the deflector. We can move it on the order of a couple of inches, at high field, so this gives us typically a 1-Mev shift in energy at both 13 Mev and 6 Mev, where we recently made measurement on this effect.

Probably the most important use of our poleface windings has been to enable us to use a fixed mechanical position of our deflector system plus external plumbing and then aim the beam down the throat of the thing. Since the frequency is variable, our acceleration conditions change somewhat. If the deflector position is set for one frequency, you generally find that the beam is not aiming right if the frequency is changed. So, we can use these windings to swing the angle of approach back into the deflector by up to 3°, if necessary. By the use of these poleface

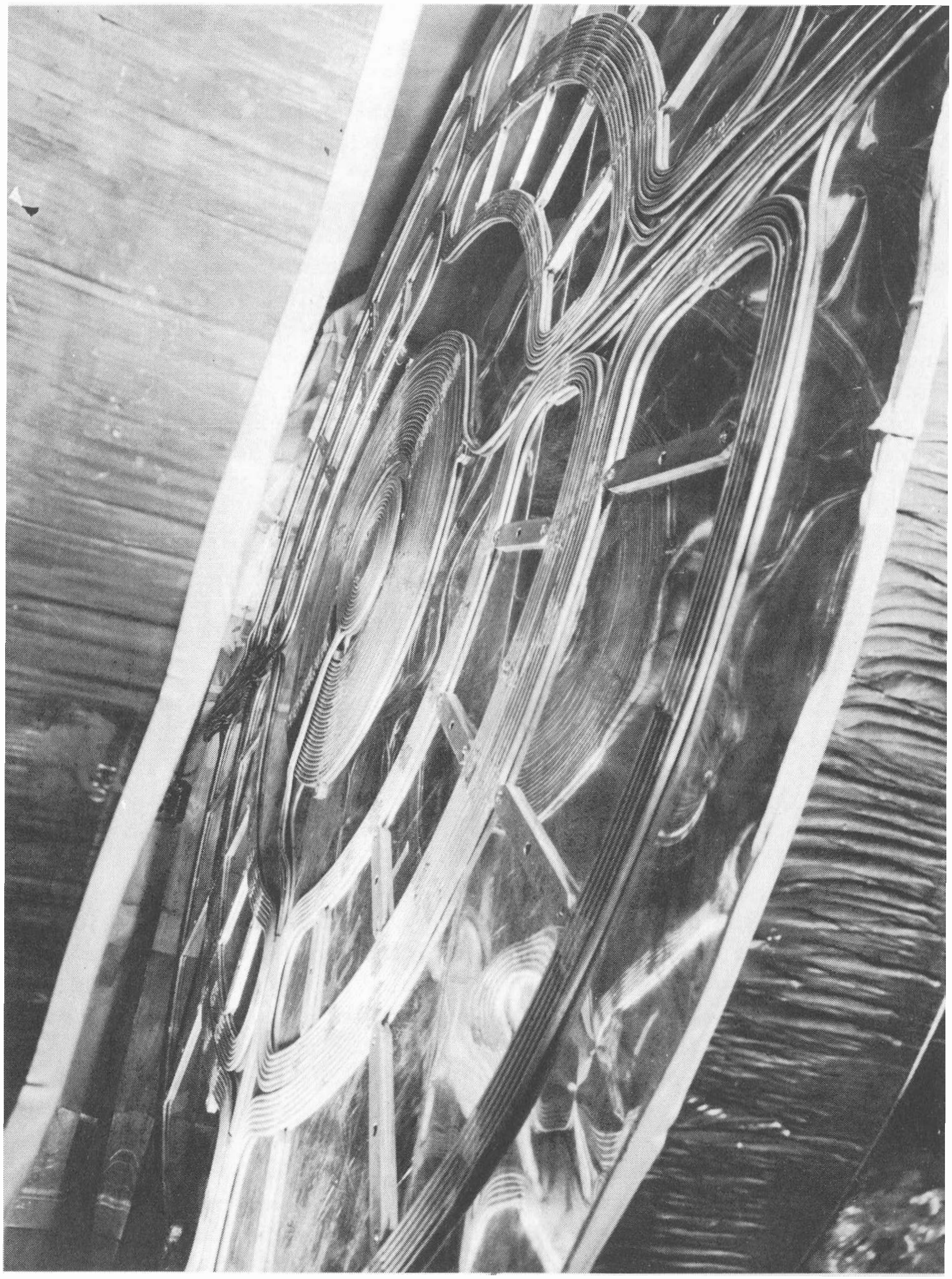

Fig. 228. Photograph looking into the magnetic gap of the 90-inch cyclotron and illustrating the various poleface windings.

windings with a fixed mechanical position of the deflectors, we can always get the beam out.

One other small point of interest, perhaps, is the septum. We have had a lot of trouble with the septum burning up, and just recently we copied the Oak Ridge "picket fence" -- that is, the aluminum pickets with water streaming through them. This seems to be a big improvement over our old system, although we burnt the first one up. We don't know why yet.

Figure 228 shows our poleface windings. This a view looking into the gap, showing the edges of the polefaces. At the center of the machine we have some circular windings for peaking up the field near the center for axial focusing. Next we have two sets of quadrant coils, one at an inner radius and one at an outer one, centered over the final accelerating orbit. We heartily recommend their use. We could not do without them.

W. I. B. SMITH: Do you find both sets of poleface windings useful? I mean, do you recommend the sets?

PETERSON: The quadrant coils are most useful and most critical, I would say. Usually, I think, we run with almost no current in the central coils, although I remember that in the early days the beam seemed sensitive to the very center coil, but recently it isn't. It has to do with the various mysteries of the ion source, I believe. I blame all troubles not understood on ion sources. I think you need at least two sets of quadrant coils if you are going to use them both for aid in deflection and in shifting energy.

HUDSON: What is the coil construction?

PETERSON: They are of insulated, coaxial construction, and similar to those displayed here earlier except that they are smaller; they are 1/4 in. diameter, roughly.