General Discussion C

SYMON: Since people still compare the smooth approximation results with computer results, I would like to make one comment with regard to the way in which it should be applied, perhaps to account for why some people get better results than others. In the case of an accelerator which is non-scaling, like a cyclotron, one has to be careful about the definition of the quantity k. The proper way to define it is $k = (R/\bar{B})(d\bar{B}/dR)$, where $\bar{B}$ is the magnetic field averaged along the equilibrium orbit and where R is the mean radius of the equilibrium orbit, i.e., the length of the orbit divided by 2π. That is a rather difficult thing to calculate, since you have to know the equilibrium orbit in advance. Fortunately, in the case of a cyclotron, if the magnetic field is exactly isochronous, then one can prove rigorously that $1 + k = (1-\beta^2)^{-1}$, where $\beta = v/c$. The smooth approximation then gives you, for example, $\nu_r = (1 + k)^{1/2} = (1 - B^2)^{-1/2}$. This value will be better if one simply takes the field average along a circle and uses the radius of the circle in computing k. For example, the formula above can never give a value of ν_r that is less than 1.

Dr. Terwilliger tells me that his ν values were calculated with this formula for k; this is possibly the reason he gets somewhat better agreement than other people.

CHAIRMAN JUDD: The point then is that these symbols being cast around may differ in definition according to how careful one is, and you get the best result only when you use the best prescription.

WELTON: I think probably another important point there is that Dr. Terwilliger's machine has a lot of spiral and not much flutter.

CHAIRMAN JUDD: This may be advantageous if your only objective is to get agreement between two different ways of getting an answer.

BOYER: We have made some measurements in the central region; I will describe the geometry of the center of our machine very briefly. This is the ion source, and the puller bar is curved so that in looking down on it, it looks something like this, where this is the slot and this is the source of the ions, and it has a three-fold asymmetry focusing in the center. It has about ±5% flutter, and due to the mechanical construction rather than other reasons, is has a falloff of about 0.75% in the first 1.5 in. or so of radius.

We made measurements of what the beam did as a function of the ion source height, what kind of beam falloff there was as a function of radius, and what the beam spread was as a function of radius. We found that by increasing the effective source height up to about a 1/8 in. ±1/16, one gained in intensity at the full radius, with greater source height there was no gain. We observed the pattern on fairly small graphite fingers to see where the beam hit. At about 4 in. radius, the closest we could approach the ion source, the beam is about 1/8 in. high. It continues 1/8 in. for about two gap widths, to between 8 and 9 in. radius; there it is about 3/16 in. high. Farther out it narrows back to 1/8 in., and nearing the deflection radius (approaching the 0.2 resonance) the beam widens to 1/4 in. in height.

When the r-f is adjusted for an optimum beam at the puller radius, there is essentially no loss of beam from 4 inches to full radius; the beam is constant in intensity, showing that there is no penumbra around the beam. If we increase the height of the ion source this is not true; the beam does change with radius, and you seem to lose beam arising outside of these limits in the first half of the radius of the machine, consistently. We have gained nothing but stray beams by increasing this height; we seem to capture only that part of the beam that is in this 1/8 in. However, so far this has not proved to be much of a limit. We have gotten as much as 5 ma of protons with this kind of ion source and about 1 ma of alpha-particles.

We have also put a guard on the side of the ion source, about 1/16 in. wide and about 1.5 in. away, where one would calculate it should go if the ions are in phase with the rf and gained the maximum available energy. The resonance condition is the same as that required for the deflected beam. We experience some loss due to this slit, although it is possible to increase the ion source intensity and increase the current through this slit, indicating that apparently we are deflecting mainly ions that are extracted in phase with the radio frequency.

There is one further thing that was done on the previous machine. We looked quantitatively at the axial distribution; when it had only a radial-falloff focusing, we found that the beam was much wider. It had a full-width half maximum of a little over 1/2 in., but the beam would make a vertical oscillation and hit a dee; it was bunched all the way. We had a multiple-head probe with which we could locate the maximum intensity, the position of which was sensitive to changes in the dee. The position moved up and down with changes in the temperature of the dee. You could see the beam walk up over the face of the probe as the dee cooled off, showing that there was some vertical motion which is not generally considered in calculations. This is something that we don't understand analytically as yet.

TENG: Dr. Lind, you assume simply a point source, that all the particles come in at the same point. Do you have the same calculation with particles coming out at different points?

LIND: We took different heights in the vertical plane and also different angles. Well, not exactly that. What we did was rotate the whole structure with the puller also. This would not give the same starting condition, but approximately, I think would give small angles. We found that the orbits rotated by just the amount the puller-ion-source assembly was rotated.

TENG: The ion source has a certain finite extent.

LIND: We didn't actually keep a radial account of the ion source.

TENG: It might be interesting to take the different points.

LIND: I think the reason we didn't see anything very significant is because we did not have an accurate method of calculating the impulse given to the ions in traveling from the source to the puller. The fields in that region used in our procedure were not very accurate; the exact focusing property of the plasma interface and the field through the core were certainly not well represented.

TENG: I have a remark about this k mentioned by Dr. Symon. Since 1 + k is essentially the momentum compaction of $\frac{r}{p}\frac{dp}{dr}$, I always find it much easier to calculate k if I calculate the momentum compaction minus 1. I don't know why people use k at all, since it is rather difficult, as Dr. Symon has pointed out, to calculate that average field.

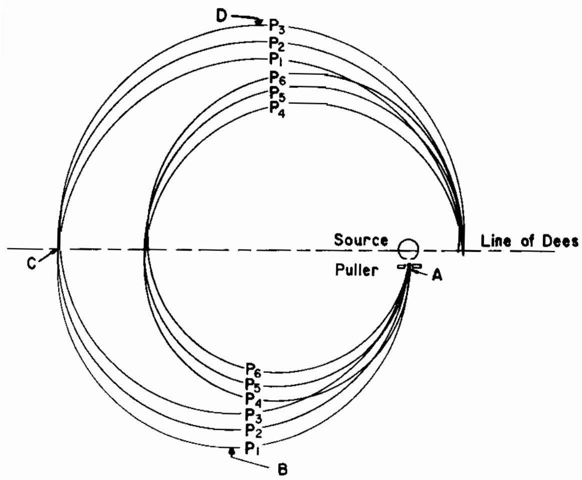

Fig. 68. Betatron and phase focusing near the source.

BLOSSER: Considerable care must be exercised in planning an aperture to define the beam extracted from an ion source. The direction of ions coming out of a source have been checked fairly well experimentally. For an ion source, such as Figure 68, with a puller, regardless of whether it has one finger or two fingers, there is an effective optical source at point A. The ions at this point have a spread in direction and a spread in space. A group of particles emitted from A at a fixed instant of time will refocus in normal betatron fashion at approximately 180° and 360°, as shown. Particles coming out at a different instant of time, equivalent to a different r-f phase may follow paths P_4, P_5, and P_6. These particles will also go through a betatron focus at 180° and 360°. The paths of both groups will coincide quite closely at 360°; we say that it is both a betatron focus and a phase focus. Lind's calculation include only the phase focusing part - only orbits P_2 and P_5. There are several experiments which indicate that at point B the betatron spread has an amplitude of 1/8 in., that P_1 and P_4 each deviate by 1/8 in. from P_2 and P_5, respectively. To select a particular r-f phase the aperture must be placed near an anti-node of the phase focus; to maximize transmission it should be near a node of the betatron focus, or in terms of the figure it must be near point C. If it is put in the dummy dee, at point B as Lind is proposing, hardly any beam goes through because it trims both the phase spread and the betatron spread.

LIND: No, we propose to put it essentially on the edge where you say the crossover is.

BLOSSER: If it is there it gives a big axial focusing impulse, which would override all the other effects in your calculations.

LIND: You can put it behind the dummy dee, so that it is almost entirely out of the field.

BLOSSER: It looks to me extremely difficult to get it out of the field and also at this focal point.