Ion Source and Beam Quality Studies

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The ion source studies in connection with the ORIC cyclotron have been conducted with the ORNL 44-Inch Cyclotron, the 63-Inch Cyclotron, and a d-c ion source test unit. As you may remember, the 44-in. cyclotron is a developmental cyclotron operating in a 6,400-gauss field with a maximum radius of 20 in. and produces 5-Mev protons. It has a maximum dee-dee voltage of 200 kv and a dee aperture of 6.5 inches. Both ion source and ion transmission studies have been made with this machine.

Figure 204 shows some selected ion beam attenuations from the 44-in. cyclotron. These attenuation curves were selected for minimum attenuation from a number of runs. The runs from which the curves were taken were made in an attempt to determine why the attenuation of high density beams is greater than low density beams. A small ion beam almost always has significantly less attenuation regardless of the cause of the small beam. The two top curves are about the best obtained on the 44-in. for high current, yet their attenuation is greater than the lower curve which is somewhat typical.

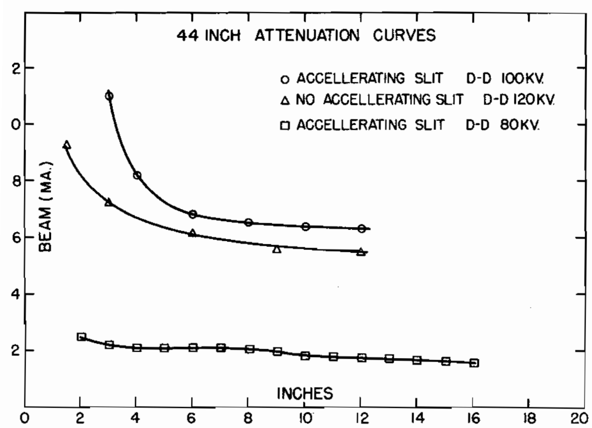

Fig. 204. Beam attenuation in ORNL 44-inch cyclotron.

An interesting effect of ion-current intensity at lower dee voltage is shown in Figure 205. These three curves were taken under identical conditions with one exception, the amount of beam intercepted by the accelerating slit. The first curve was made by optimizing the ion current on a probe near the ion source. The second curve was obtained by moving the source so that the beam was partially blocked by the accelerating slit. The bottom curve was obtained by moving the source further. Since the arc slit and the accelerating slit were both 3/32 in., the total movement of the source was approximately 1/16 inch. The same effect is observed regardless of which side of the accelerating slit intercepts the beam. It has been observed that the accelerating slit always intercepts part of the beam when one adjusts the source position for optimum beam at 10-in. radius. The easiest explanation of this is probably space-charge effects; it may be the most difficult to accept. Space-charge conditions are difficult to evaluate since there may

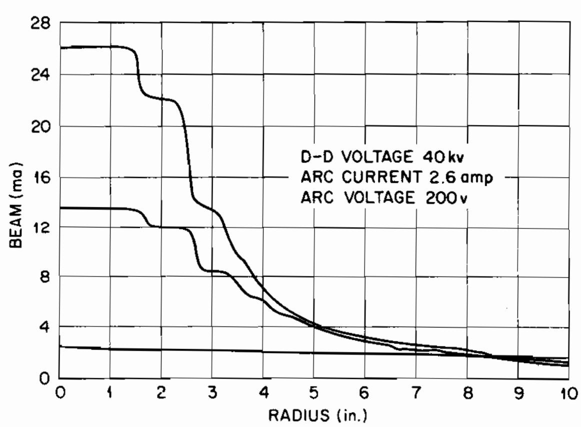

Fig. 205. Effect of location of accelerating slit.

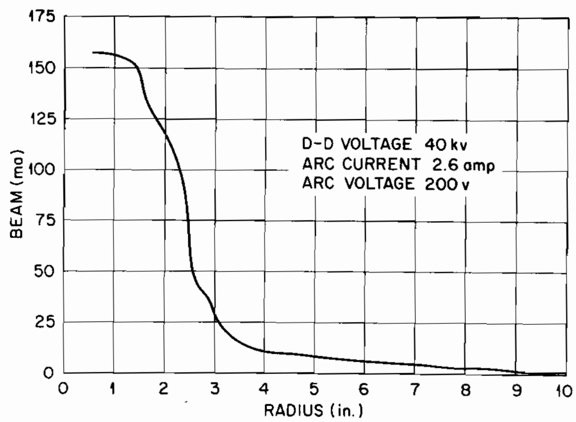

Fig. 206. Attenuation of beam from grid-type ion source.

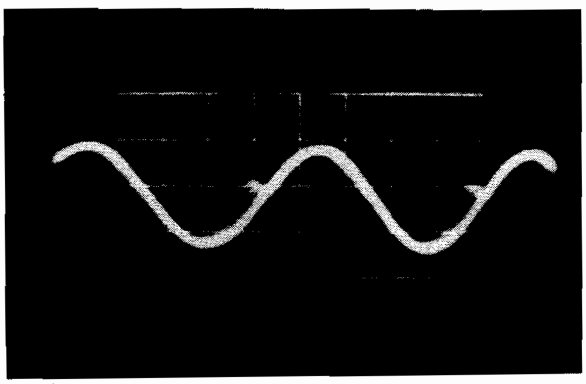

Fig. 207. Beam signal superposed on r-f signal.

well be a cloud of positive ions around the source created by low energy ions emerging on either side of the acceptance phase.

Figure 206 shows some results of tests designed to increase the ion output of a cyclotron by brute force. A grid-type source and accelerating slit was installed in the 44-in. cyclotron. The ion source had 12 slits 1/16 x 1 in. parallel to the magnetic field, with a total source aperture of 3/4 in.^{2}. This resulted in plenty of output as you can see from this curve that shows 155 ma, but the attenuation is rather sad. Ion sources with slits perpendicular to the magnetic field were tried in an attempt to use the shaping of the arc meniscus to eliminate some of the attenuation. Similar results were obtained in both cases. I think little effort would be required to obtain ion beams in the order of one ampere; however, considerable effort would be required to get a significant improvement in beam quality.

Getting back to reasonable ion beams, an attempt was made to observe the phase shift and distribution of ion groups. Figure 207 shows an oscilloscope picture of a beam signal superimposed on the r-f signal. Our equipment was not fast enough to obtain good information; however, the phase shift of beam with respect to radius was observed. The significance of the picture is the indication that an ion beam signal did not occur on every cycle.

The conditions are more clearly shown in Figure 208. The r-f signal was minimized and is the bright portion at the bottom of the picture. The scope sweep was increased to 20 μs/cm. Thus an envelope of ion beam signal is formed. This shows an ion beam for about 200 r-f cycles and no ion beam for about the same time. The second picture shows an ion beam on each r-f cycle. The only difference in conditions for these two pictures was a very slight adjustment in arc current, of the order of 1%. The total output under each condition is very nearly equal, so this condition cannot be detected under normal operation. The cause of this is not known. Some d-c sources produce a hash under conditions of high output but this normally cannot be resolved. The conditions of intermittent output on the 44-in. cyclotron occur at random, perhaps 10% of the time.

Some typical information obtained in source studies on the ORNL 63-Inch Cyclotron are shown in Figure 209. This curve shows ion current on an internal prove vs magnetic field. It was hoped that we could determine the N^{5+} output of the source;

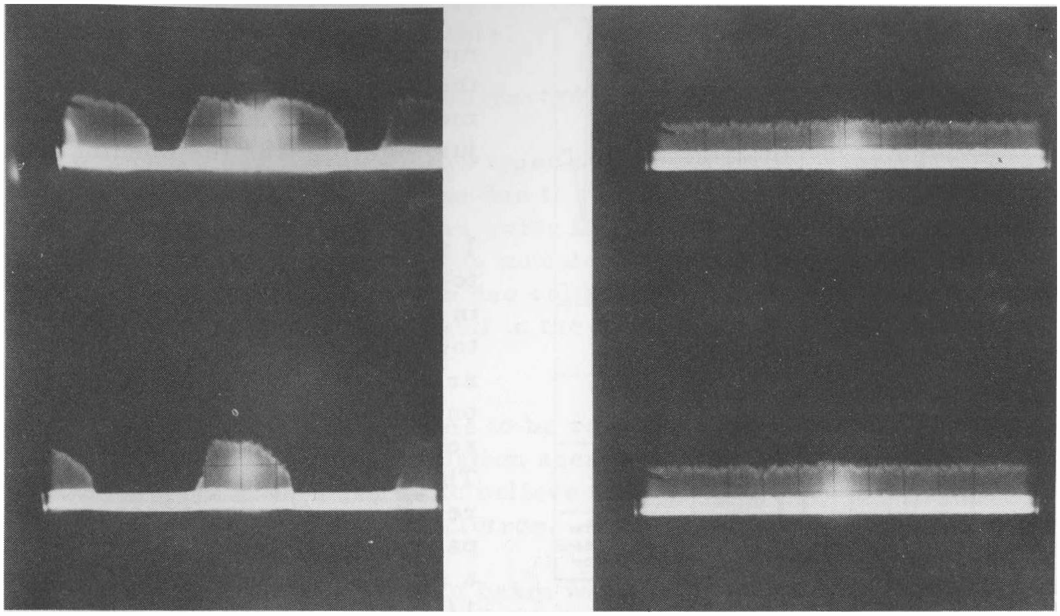

Fig. 208. Intermittent and constant beams.

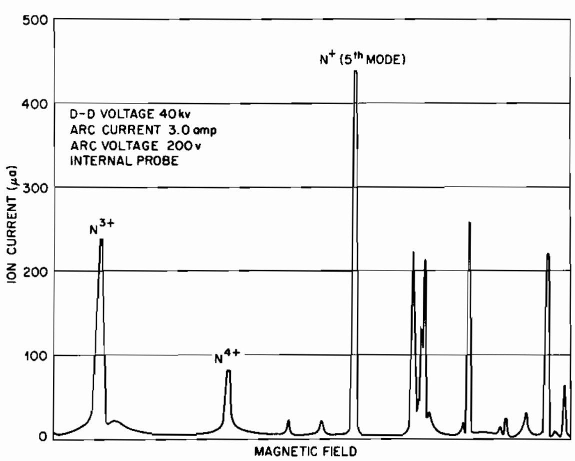

Fig. 209. Magnetic analysis of ion current in ORNL 63-inch cyclotron, at full radius.

however, the high efficiency of mode acceleration makes interpretations somewhat difficult. N^{3+} and N^{4+} are obvious, but N^{5+}, if any, is covered by N^{+} on the 5th mode.

Figure 210 shows some results from a d-c source test unit which operates in a 6,400-gauss field. Normally a d-c accelerating potential of 25 kv is used, but it can be varied from 5 to 40 kv. Scans are made with a traveling probe of 1/16-in. radial width. At the present time the probe moves along the 180° focal plane. This permits a study of ion species. The scan shown was obtained from a nitrogen arc. These studies have just begun, so debugging has consumed most of the effort, and there is still some to do. Almost any impurity, leaks, or outgassing in the source will eliminate high order ions. Some oxygen is present in this scan. The high background is caused by a weak oscillating volume around the source. Both of these difficulties need to be completely removed. Future scans will also be made in the 90° plane in order to better determine brightness or quality of the beam.

CHAIRMAN LIVINGSTON: I might add that we hope also in this unit to study this matter of phase-space density and the question of whether or not the detailed geometry of the unit can contribute to a high-density, low angular-spread beam to be injected into the cyclotron. These tests are just in their infancy.

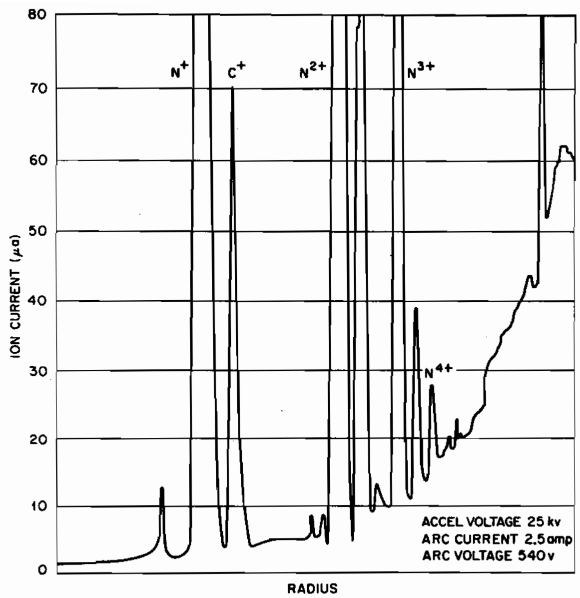

Fig. 210. Ion spectrum obtained at 180° in D-C test of source for heavy ions.

SNELL: Would you say something more about the grid source? I mean the size of the opening. I think you mentioned the number of grids, but just how big was the opening from it?

JONES: The grids were parallel, 1 x 1/16 in., arranged three slits end-to-end, parallel to source, by four slits in the other direction. This gives a total of 12 slits or a total 3/4-in. of arc aperture. The curve that you saw on the slide was taken from an ion source with this type of arrangement. The curvature of the arc meniscus can result in a divergent, convergent, or parallel ion beam. To test this effect a source was tested which had 24 slits 1/2 x 1/16 in. aligned perpendicular to the magnetic field. The same results were obtained as with the parallel slits.

SIMON: I wonder whether the peculiar patterns that you got where the accelerating current seemed to come on and off were related to the vacuum conditions?

JONES: We did not test this effect. One might also explain this effect by space charge because there must be a cloud of low energy positive ions around any ion source created by ions that are emitted a little before and after the acceptance phase of the cyclotron, so we tried to determine if this really was space charge. We changed the gas pressure under normally operating conditions and saw no effect. We did not change the gas pressure under the conditions where we know we had intermittent ion signals.

SIMON: I asked the question because we have observed pictures that looked something like yours in a completely different situation with electron models. The only point is that in that case, because the orbit dynamics were thoroughly understood, it is one of the few cases I know where a complicated effect like this could be completely accounted for, and it just turned out to be control of the shape of the wiggles, and so on, that you get. It was an effect due to the ionization of the residual gas in the vacuum tank by the beam. It fills up and blows up the beam, and the beam disappears and ions go away and come back again.

PARKINSON: Is the change with dee voltage appreciable?

JONES: Not over a small range. Over a large range I don't know.

SCHMIDT: Was the average beam the same for both cases?

JONES: Yes. Unfortunately, the only way you can observe it is on the scope.

SCHMIDT: In a scattering chamber we often see these effects, but we attribute them to the tight geometry of the external extraction system. We don't even know what the cyclotron itself is doing.

WALL: We have observed exactly the same sort of effects; they are particularly troublesome in coincidence experiments.

JONES: Our conditions always corrected in our case.

BOYER: There are definitely two types of modulations. There are various external beam modulations which can be due to radial oscillations shifting the phase. We have an internal probe that we can swing into the beam any time and look at it with the fast scope. We see ion source modulation on the internal beam which can at times get bad enough to reflect in the dee voltage. There are several separate modulations due to the ion source itself in the internal beam as well as these effects due to the deflection.

WALL: our external beam seems to be relatively independent of the dee voltage over quite a large range. The modulation seems to stay the same as we vary the arc conditions. This has always led us to believe that it was an effect of pulling the beam out at a particular location in the cyclotron.

MacKENZIE: This attenuation of beam with radius seems to fit in at Berkeley with what you would expect from space charge loss. It seems to be the right order of magnitude.