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CENTRAL REGION STUDIES FOR INCORPORATING AN AXIAL ION SOURCE IN THE DAVIS 76-INCH CYCLOTRON

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The 76-inch Davis cyclotron is essentially a copy of ORIC*, and full scale magnetic field measurements have shown that the fields of the two machines are nearly identical except in the central region (at radii of less than 12 inches)[1]. The axial ion source originally designed for the 88-inch cyclotron at Berkeley[2], has been installed in the Davis machine from the bottom of the magnet. It is contained in an 8 inch diameter steel plug which passes through the lower pole of the magnet.

Before construction of the Davis cyclotron began, model studies were made on the 0.275 scale model magnet at Oak Ridge to determine if a satisfactory magnetic field could be achieved in the central region using the Berkeley ion source. The results of the model studies[3] showed that proper focusing could be achieved at most field levels by locating the "top" of the 8 inch plug 6 inches from the valley floor and removing the upper central ring shim from the ORIC design. This shim is shown by the dotted line in figure 1.

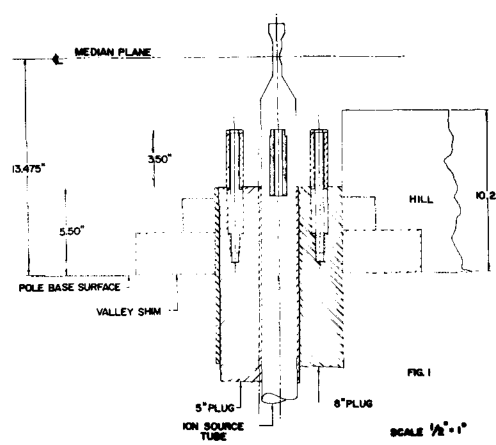

Fig. 1 Ion source and central region iron geometry.

However, it was not possible to operate the model magnet at the extremely low (3.5 kilogauss) field levels at which we might like to operate the full scale machine. The full scale magnetic field measurements subsequently showed a depression in the radial profile at low fields which had strong defocusing characteristics. Since the turn separation in a 3 kilogauss field is large, a poor radial profile might be unimportant, except that the ion source position is limited to a maximum radius of 2.5 inches. This forces operation at comparatively low dee voltages (20-30 kv) in order to center the orbits, and the ions are forced to spend too much time in a defocusing field. (Aside from mechanical design difficulties, the radial position limitation is apparently the chief disadvantage of the axial ion source.)

Figure 2 shows the full scale radial profiles of the iron field resulting from the original model design compared with the profiles of our final design and the ORIC iron. (The ORIC data shown is from the original full scale field measurements and at present ORIC has some additional iron in the center which would remove the depressions shown.[4]) The final design called for moving the 8 inch plug to 5.5 inches from the valley floor and to extend the caps to a length of 3 1/2 inches. These caps saturate at high levels, but fill in the central "hole" at low fields. The flutter of the two machines is nearly identical, but the installation of the Berkeley ion source had no discernable effect in this regard.

Figure 3 shows the isochronous and operational radial profiles on which the results are based. The isochronous fields are obtained with trim coil settings computed by a linear program, and their greatest deviation from isochronism is less than 15 gauss in all cases. The isochronous conditions used as standards were computed with the formulas of Smith and Garren[5]. Trim coil number 1 was used to provide the radial bump for focusing in the low-flutter region to supplement electrostatic focusing. The phase excursions in the tested fields as computed by the Crocker Nuclear Laboratory orbit code[6] are shown in figure 4. The medium and high field cases were run with 70 kv on the dee, and the low field cases with 30 kv. In all of the cases the field becomes isochronous where the phase approaches zero. The starting conditions for all cases were estimated by starting the ions on an equilibrium orbit of 12 inch radius and de-accelerating them to the center. The conditions thus obtained were used to start the ions and all data shown is from acceleration tests.

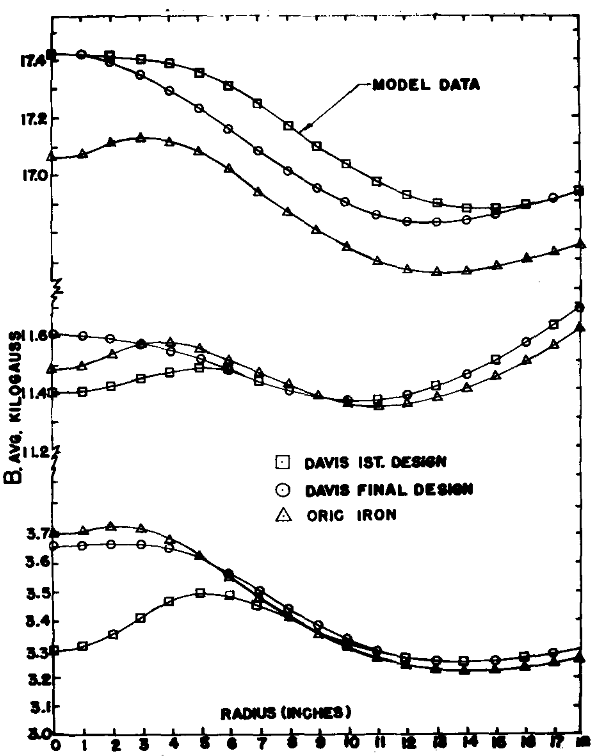

Fig. 2 Changes in iron profiles caused by modification of plug position and cap size.

Empirical evidence obtained from recent start-up data from 42 MeV α-particles show that the beam measured at extraction is augmented by possibly 10% by using 22 amps in trim coil number 1 rather than -145 amps. The former produces the central radial bump and the latter produces the isochronous medium field profile in figure 3. Figure 5 shows the axial betatron frequency computed by the orbit code for the fields studied. Figure 6 shows the radial betatron frequencies. The particles pass through the 3/3 resonance at a radius of 6-7 inches. The computer calculations show that the radial oscillation build-up at resonance is not excessive and soon damps to ~0.3 inch.

We have not attempted to obtain particle beams for the cases discussed here as we do not plan to accelerate protons until the shielding vault is completed. However, the validity of

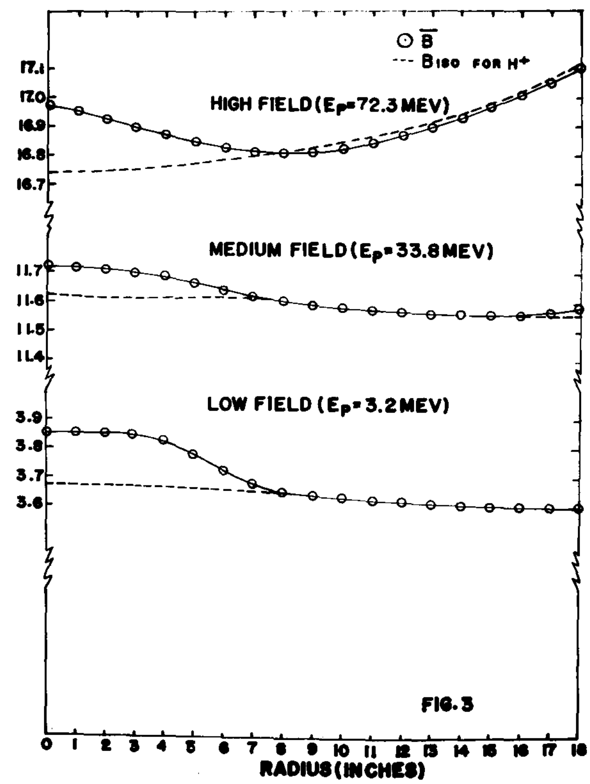

Fig. 3 Operational fields profiles achieved by trim coil adjustment.

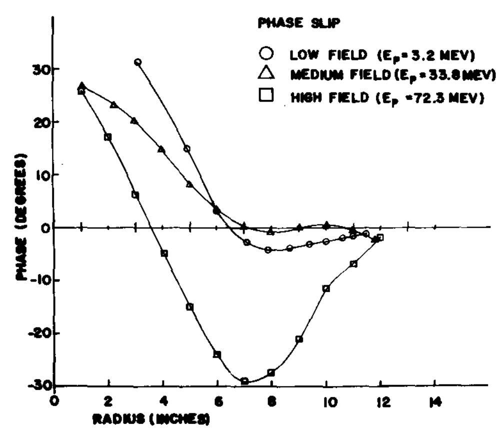

Fig. 4 Phase slip for computed cases.

of the calculations and magnetic field data is supported by the fact that we obtained an internal beam of 21 MeV H_2^+ ions using the computed field on the first attempt. It is believed that the installation of the axial ion source will contribute to reproducible operation as well as making possible future axial injection through an identical 8 inch axial hole in the top of the magnet.

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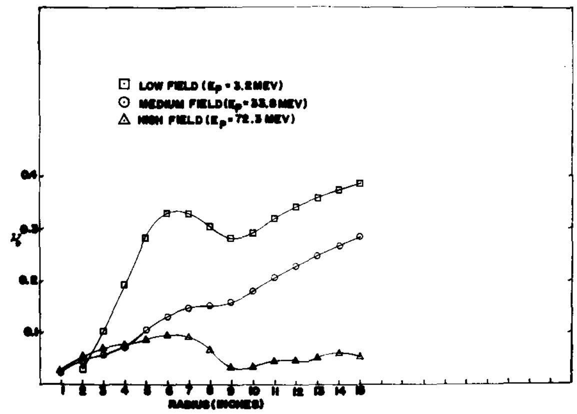


Fig. 5 Axial betatron frequency.

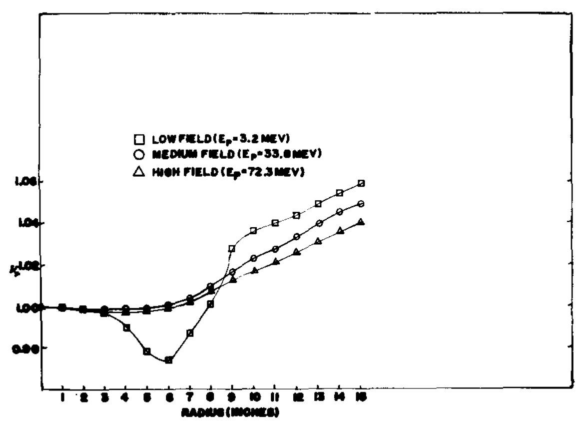


Fig. 6 Radial betatron frequency.

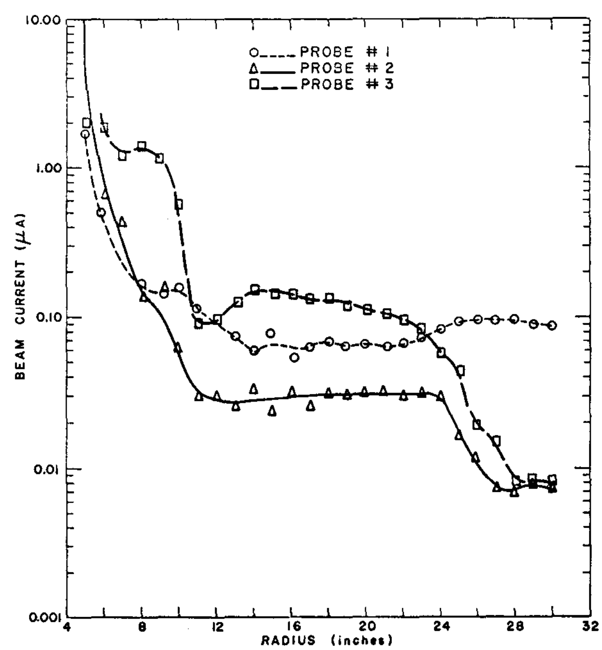
References

1. J. A. Jungerman, Davis 76-Inch Cyclotron Progress and Status, February 1966 (Submitted to this conference).
2. P. G. Watson, Nucl. Instr. and Meth. 18, 19, (1962) 362.
3. L. J. Kibbe, Crocker Nuclear Laboratory Report CNL-UCD 22 (July 1964) (unpublished)
4. W. H. White, private communication.
5. L. Smith and A. A. Garren, Lawrence Radiation Laboratory Report UCLRL-8598 (Janary 1959).
6. F. P. Brady and L. W. Baumhoff (unpublished).

Addendum

JUNGERMAN: On behalf of the staff of the Crocker Nuclear Laboratory at the University of California at Davis, I am delighted to announce that we achieved an internal beam in the cyclotron on April 8th of this year. This was done 29 months after the start of engineering. The first beam was obtained with just four trim coils operating, so we lost isochronism at 20 inches. Since then, with eight trim coils operating, we observed 3 μA of molecular hydrogen ions at the 30-in. extraction radius. The 21-MeV energy of the H_2 ions was chosen to confirm settings given to us by the Oak Ridge National Laboratory. It was very comforting, indeed, to have these trim-coil settings available in making this initial attempt. Actually, we started up the beam on our own linear programming settings, and only had to change the main magnet setting to get the beam.

The first slide (not available) shows the cyclotron as it now appears. Those of you who are familiar with ORIC will recognize the resonator tank. The magnet incorporates the historic 60-in. Crocker magnet which was moved to Davis from the Berkeley campus. The shielding is only in part installed; the roof shielding will be installed about the end of this June.



This next slide shows very preliminary results; in fact, these were obtained Tuesday and Wednesday of last week. The data is from measurements on a radial probe with three 3/16-in. elements. It is encouraging that at the extraction radius over 85% of the beam is on one 3/16-in. element. These curves were taken with 42-MeV alpha particles, to obviate the difficulty of gas-loss correction. The alpha-particle beam was obtained, with no difficulty, on the same settings as H_2^+.

