SPIRAL-SECTOR FFAG MAGNET DESIGN AND FIELD MEASUREMENT(*)

S.C. Snowdon, R.S. Christian, G. del Castillo and R.W. Fast
Midwestern Universities Research Association, Madison
(Presented by S.C. Snowdon)

Any practical realization of a scaling spiral-sector FFAG magnetic guide field must incorporate radial cuts to permit the insertion of the RF acceleration fields and to convert the magnet field to manageable modular units, see Fig. 1. When these radial cuts are inserted at uniform intervals around the magnet ring, the desired symmetry property of the magnetic field is obtained if the coil excitations are adjusted such that the fields under the center of each plus pole are proportional to r^k. The calculation of the magnetic field throughout the entire magnet is then reduced to a calculation within a unit cell of the magnet, the ratio of fields at homologous points in any two cells being determined by the ratio of r^k to the centers of each cell.

As one proceeds outward along the spiral ridges, a point is reached at which the flux density in the plus poles attains high saturation levels. This can be eased by a change in the pole structure. Since the vertical oscillation amplitude of the beam has been reduced by adiabatic damping, it is possible to use shaped poles which are surfaces of constant magnetomotance. In effect, this reduces the flux density for a given median-plane field and also reduces the ampere turns required to excite the pole.

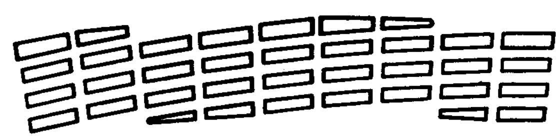

Fig. 1 Magnet superperiods.

Fig. 2 shows two magnet blocks suitable for a 30 meter radius accelerator for which the fields were calculated by iterative computer techniques. The fields were measured on the median plane with a reproducibility of a few parts in ten thousand with a rotating coil and digital-voltmeter system. Fig. 3 illustrates the rotating coil housing and part of the positioning system used to step the coil along in a rectangular mesh throughout the area of interest.

The first problem was to determine the manner in which correction coils should be added to account for all the magnetomotance drops in iron. To this end, it proved of value to predict the value of the fields under the centers of the plus and zero poles by use of a magnetic circuit that incorporated the saturation properties of the normal induction curve in the reluctance elements of the circuit. Only geometrical estimates were made to determine the various reluctance elements, apart from the use of a normal induction curve appropriate to low-carbon steel. Again, an iterative process was employed to solve the 15-loop non-linear circuit. Solutions were obtained for 20

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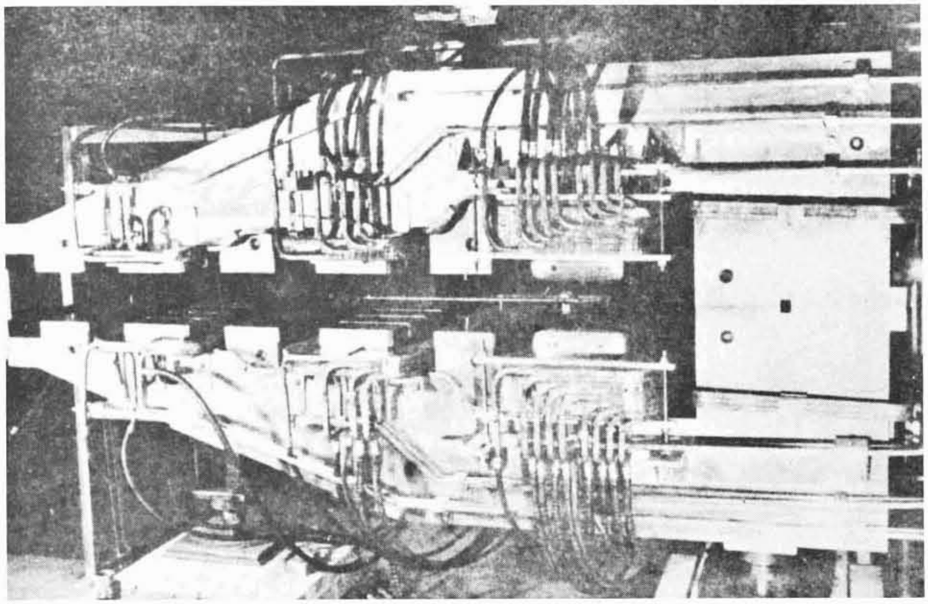

Fig. 2 Magnet blocks suitable for an r = 30 accelerator.

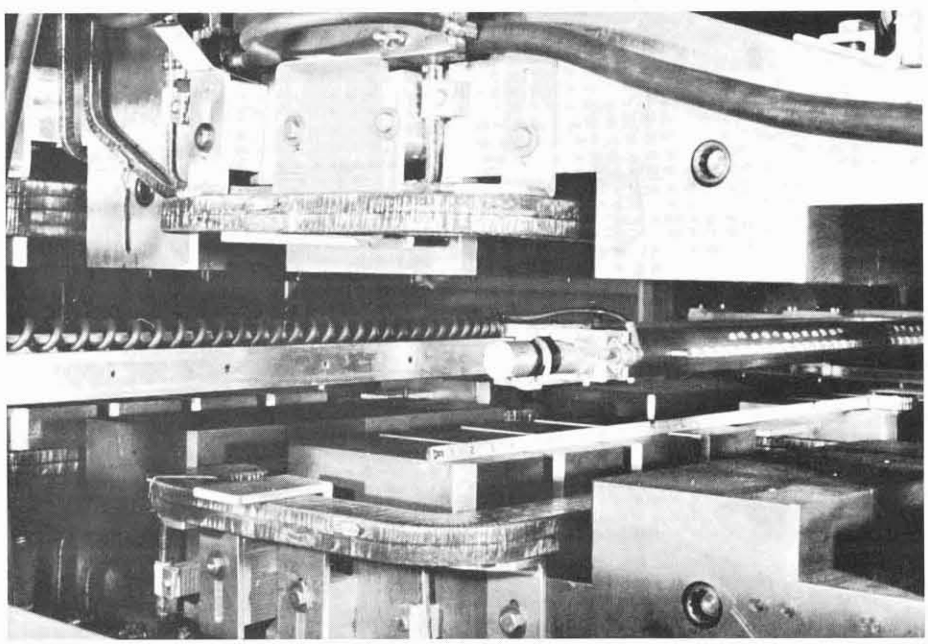

Fig. 3 Field measuring equipment.

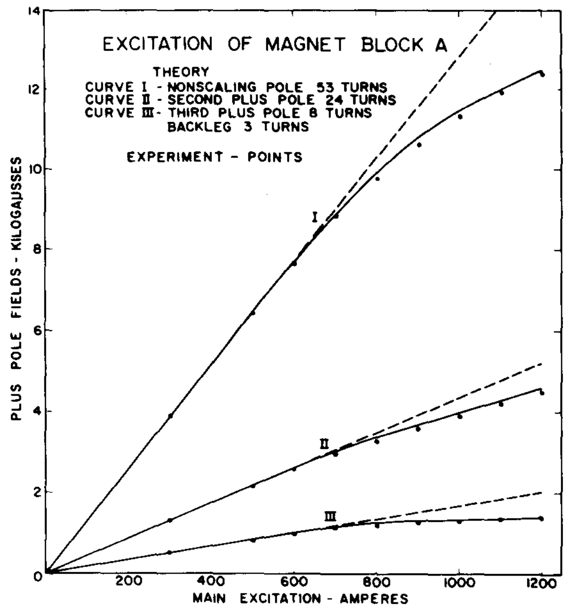

Fig. 4 Measured fields and circuit theory estimates.

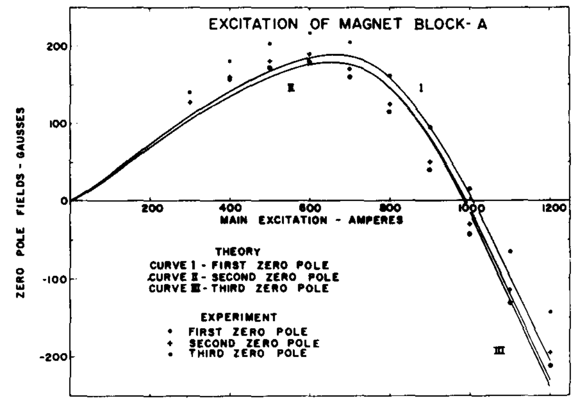

Fig. 5 Fields from Fig. 4, corrected.

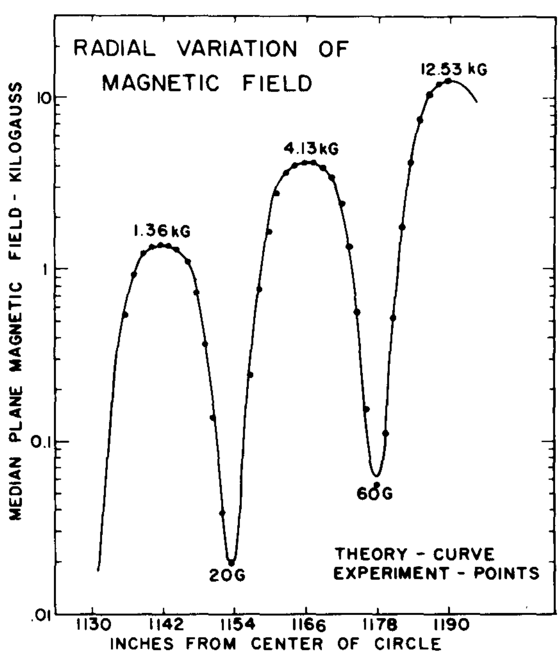

Fig. 6 Radial variations down center of one magnet block.

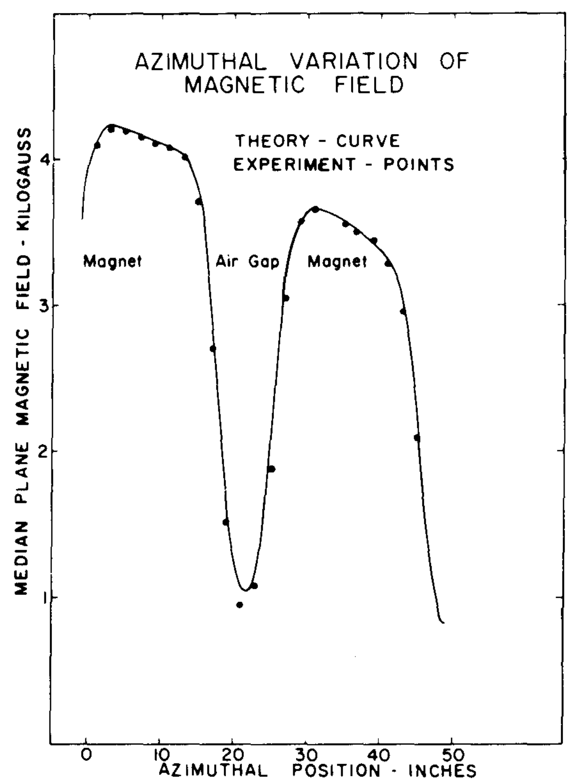

Fig. 7 Azimuthal variations across the two magnet blocks in the neighborhood of the plus poles.

excitation situations ranging from low to full excitation, see Fig. 4. The agreement between the measured fields and the circuit theory estimates is seen to be good to a few percent out of about a 30% deviation from the ideal iron case. Comparison of the circuit theory results with the desired fields at the measured points indicates the changes in excitation that are necessary. These corrections were applied, with the results shown in Fig. 5.

After minor trimming of the various excitation currents by means of water-cooled shunts, the magnetic field was mapped as shown in Fig. 6 and 7. In each case the agreement with theory was quite good. The percentage deviation between the measured and calculated fields is indicated in Fig. 8 and 9. The deviations near the scaling poles of about 1.5% may possibly be accounted for by saturation in the corners, as was indicated by a calculation in which these corners were removed by beveling. The difference between beveled and non-beveled calculations gave exactly the same curve as obtained in Fig. 8.

The discrepancy indicated in Fig. 9 for the azimuthal run is more difficult to account for. Lowering the coil 1/4 in. removed the discrepancy. This seems to indicate that the drop in potential in the iron between the pole face and the coil is the source of the difficulty. Further studies are in progress to determine the difficulty. It may be noted in Fig. 8 that much smaller deviations occurred near the shaped plus pole indicating that the contouring removed the corner saturation difficulties. In any case, it appears that the method employed to obtain a spiral-sector FFAG magnetic field can with a slight amount of empirical adjustment, be made to yield magnetic fields that are within a few tenths of a percent of the calculated fields. It is hoped that further study will reduce this discrepancy still further.

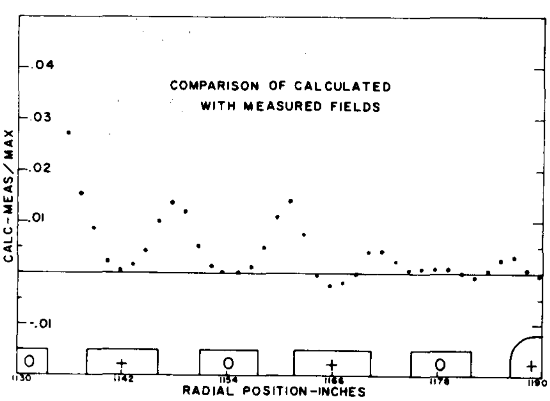

Fig. 8 Deviations in radial measurements.

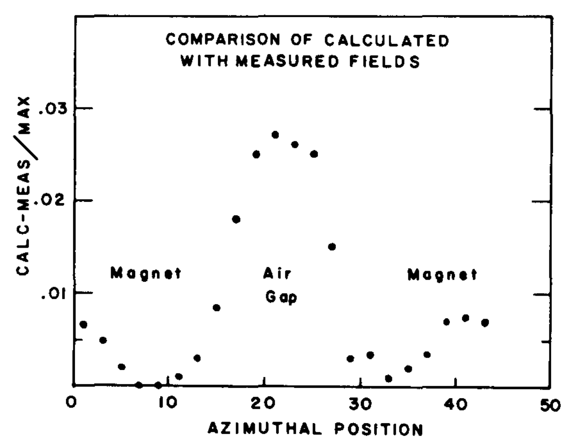

Fig. 9 Deviations in azimuthal measurements.