MAGNETIC FIELD CALCULATIONS OF THE NSCL K800 SUPERCONDUCTING CYCLOTRON MAGNET*

L.H. Harwood and B.F. Milton
NSCL, Michigan State University
East Lansing, Michigan 48824
U.S.A.

Abstract

The results of a recent recalculation of the magnetic field properties of the NSCL K800 cyclotron magnet are presented. The calculations are based on an expanded version of POISSON for the azimuthal field averages and on a two parameter uniform magnetization model for the flutter. Force calculations are also presented; large changes were found from the earlier calculations which used a much smaller lattice. Comparisons between field calculations and measurements are presented.

Introduction

Classically cyclotron magnets have been constructed after a laborious cycle of building and mapping successive model magnets. While this has by and large been successful, the cost becomes prohibitive with large magnets; secondly the construction of a model magnet for a 30-50 kG superconducting magnet can be more of an engineering challenge than a full scale magnet due to the limits of current density for present superconductors.

A very different approach was used for the design of the NSCL K500 and K800 cyclotron magnets. Computer modeling was the basis for the designs of these magnets with no modeling cycles. The successful operation of the K500 cyclotron has proved that the procedure works.

The K800 cyclotron magnet proved a more formidable task. The radius of the magnet is increased by 40%, thereby straining the computer codes used for the original modeling and putting its accuracy at risk; the larger size would also increase the forces on various parts of the magnet. We have therefore moved to enhancements in the codes used for the calculations and enhancements in the details in the calculational model. Accurate measurements of the field of the magnet have allowed reliable testing for the calculations. We will discuss here the enhanced calculations, comparisons with the data, and proposed future enhancements.

Calculational model

The calculations are broken into two parts. The first part is the calculation of the azimuthal average of the field. The second part is the flutter field. The basis for the average field is the code POISSON[1] using the NSCL version of the stacking factor.[2] The stacking factor permits one to introduce regions of the magnet which have deviations from cylindrical symmetry by using an effective permeability curve for the iron in that region. The magnet is divided into regions over which the azimuthal density of iron is relatively constant and the LATTICE input is set up accordingly. Fig. 1 shows the lattice used for the calculations discussed here. Some important changes were made in the local version of POISSON that allowed the new calculations: 1) the code was installed on the FPS-164 with a speed gain of a factor of 14 realized over the VAX-780; 2) the number of points available for calculation was increased to 40000; 3) the number of possible regions was increased to 200. These changes permitted much more detail to be introduced into the calculation and the "universe" to be enlarged considerably. Specifically, the outer boundaries of these calculations were placed at r=300. in. and z=300. in. The lattice uses 22000 total points of which 12000 are in the iron. Running time for the approximately 7000 iterations needed for convergence is 45 min. A flux line plot of this calculation is shown in Fig 2 and is compared to one used in early calculations of the magnet.

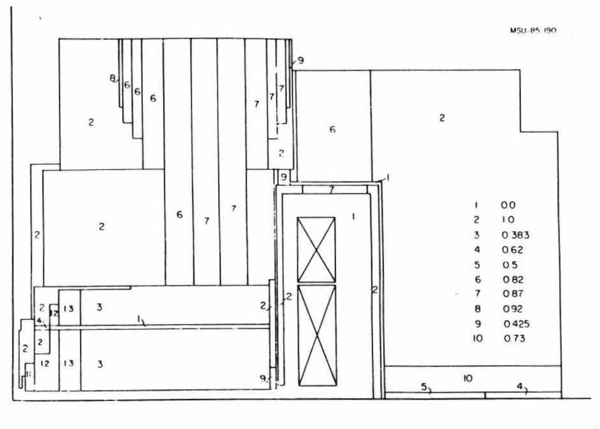

Fig 1. Lattice used for the POISSON calculations; stacking factors for the regions are listed.

An important stage of the calculations with the new lattice was the calculation of the force on various parts of the magnet. The table summarizes the differences found in force calculations using the two lattices. Fig. 3 describes the regions listed in the table. It is obvious that the change in the forces can be large, eg. a factor of 2.5 for region 3. These differences send two messages: 1) as detailed a lattice should be used as possible and 2) a large margin of error should be included no matter what the detail of the lattice.

Table 1

Forces on the K800 Magnet
(tons)

Region	Small Grid	Large Grid
1	-1440 (-1058)	-1075 (-982)
2	-52 (-244)	71 (-125)
3	13 (-64)	37 (-32)
D		-1526 (-648)
E		-185 (-62)
F		-548 (-162)
G		-520 (-211)

Entries outside parentheses are for high (+,+) currents. Entries within parentheses are for (+,-) currents.

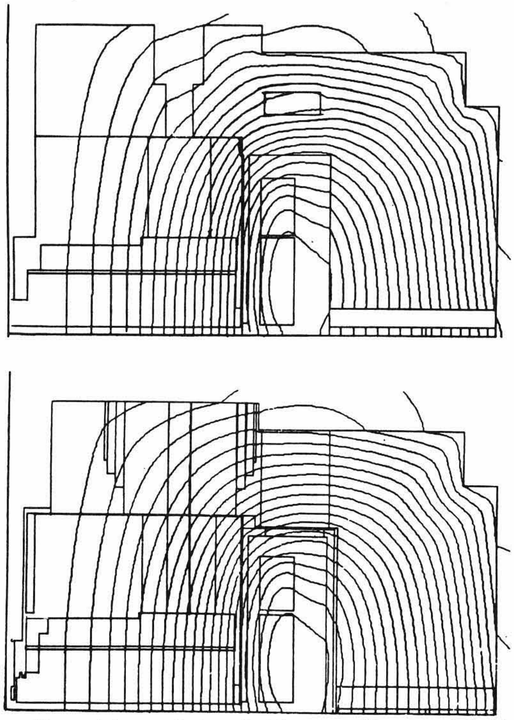

Fig 2. Flux line plot of the smaller grid (top) and larger grid (bottom).

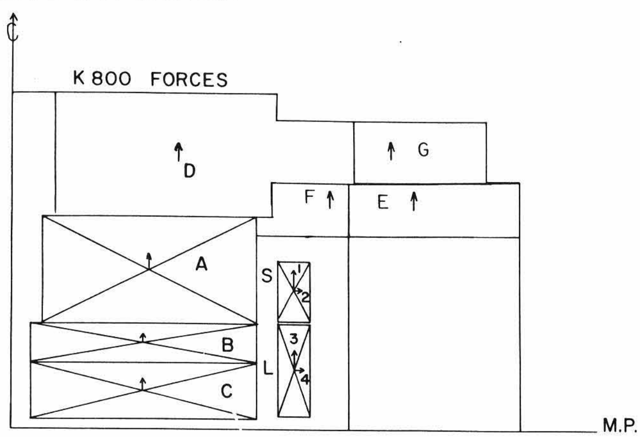

Fig 3. Magnet regions used for force analysis. Region 1 is A plus B plus C; Region 2 is B plus C and 3 is equivalent to C.

Additional detail is put into the calculation of the average field using some uniform magnetization model calculations.[3] The iron density varies more smoothly than can presently be included in the POISSON calculations; to correct for this the field of uniformly magnetized rings (with magnetizations equal to 21.4 kG multiplied by the stacking factor for the region) is subtracted from the POISSON field and then the field of the exact iron shapes, again with uniform magnetization, is added. The results of the field calculations is shown in Fig. 4 where the difference between the calculated and measured average field is plotted. The field shown is one of the better results and other excitations are not as good. The differences are less than the earlier calculations but improvements can still be made.

The flutter field calculations are based on the uniform magnetization model mentioned above. The non-cylindrically symmetric parts of the magnet are calculated with the model. The uniform magnetization model permits surfaces which have only vertical and horizontal surfaces. The rounded edges of the poles

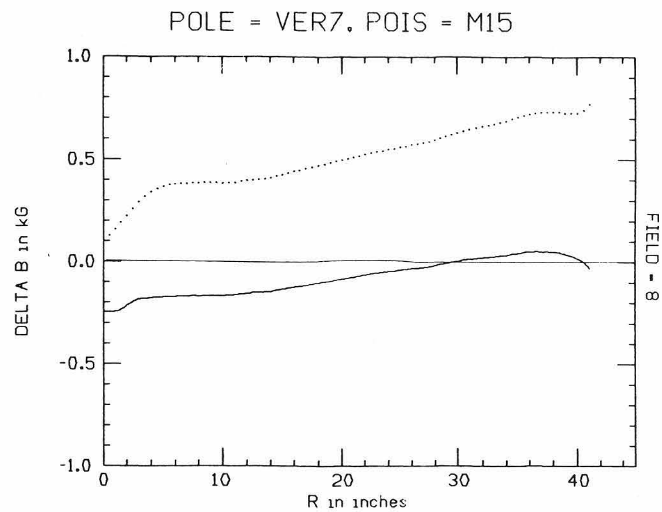

Fig 4. Comparisons of calculated and measured azimuthal averaged field. B(measured)-B(calculated) is plotted. Solid curve is for the large grid; dots are for the small grid.

tips (This rounding facilitates installation of the trim coils which are wrapped around the pole tips.) are modeled by rectangular notches in the pole edges which remove less iron from the calculation than is removed on the real pole tip. This reduction has two reasons: the distribution of iron in a vertical magnetization model would be difficult and a reduced removal of iron relative to the earlier square notch partially addresses the nonvertical components of the real magnetization distribution. The notch used was found by an empirical adjustment of the vertical extent of the notch at r=25 cm which minimized the structure in the field error at the pole edges. The net removal of iron in the notch is 30% of the actual missing iron.

The accuracy of the flutter field calculation depends critically on the value used for the magnetization. A value of 20.76 kG yields a flutter which matches the measured flutter quite well, as shown in Fig. 5. While the exact value of the saturation field of the iron in our magnet is not precisely known, some sources give a value of 21.2 kG for low carbon steel while others give 20.8 kG. The saturation field for our magnet iron is undoubtedly higher than 20.76 kG as preliminary results from of a study with POISSON of two-dimensional pole tips indicate than the reduction in flutter due to the azimuthal components of the magnetization of the pole tips is about 2%. Thus, a saturation field of 20.2 kG would agree with the flutter quite well. Additionally, the POISSON calculations were done using a saturation field of 21.4 kG; modification of the permeability curve to accomodate the reduced saturation field could bring the average field calculations into better agreement with the data. Such a study is presently underway.

Future improvements

Several avenues of investigation are open. First, utilization of the POISSON calculations for the flutter appear promising. A further step would be to utilize the magnetizations found by POISSON in the r-z and θ-z calculations in a 3-d integrations of the flutter and average field of the poles. Inclusion of the flutter produced by sections of the magnet which are not presently included would also improve the flutter; for example, eventhough the cryostat inner wall is cylindrically symmetric, it magnetization would have azimuthal variations due to the field of the poles. This last modification would affect both the average and flutter fields. We plan to further upgrade our POISSON to permit each triangle of the lattice to have a different stacking factor; thus the major discontinuities in the stacking factor would be

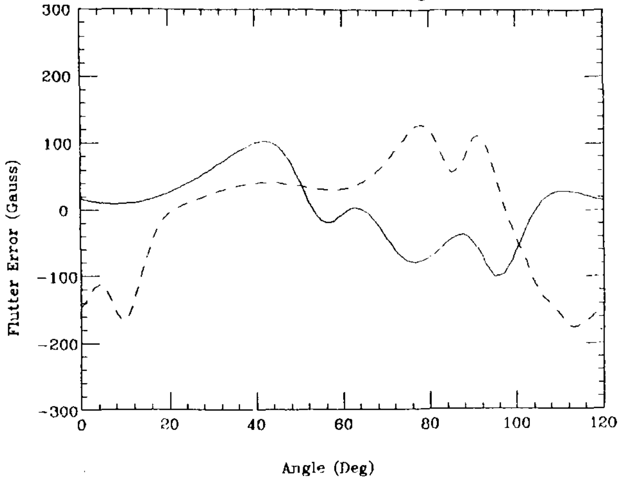

Fig 5. Difference in calculated and measured flutter field is shown for full field at r=10 in. (solid) and r=30 (dash).

eliminated. As mentioned previously, modification of the permeability curve used in the POISSON calculations is under study. The ultimate approach is a 3-d calculation; software design and mathematical models are presently underway as no existing code, eg TOSCA or GFUN3D, can address the problem in sufficient detail.

Conclusions

The field calculations for 30-50 kG cyclotron magnets are presently good enough to permit construction of full scale magnets without small-scale modeling. These calculations are not accurate to 0.1% at all excitations of the magnet, but several promising avenues of improvement are being tried which could lead to such agreement.

References

1. R. Holzinger, private comm.
2. L.H. Harwood and D.A. Johnson, Proc. of 10th Int. Cycl. Conf., (1984) 99.
3. M.M. Gordon and D.A. Johnson, Part. Accel. 10, 217 (1980).

*Work supported by the National Sciences Foundation under Grant PHY-83-12245 and PHY82-15585.