BUILDING A FAMILY OF CORRECTOR MAGNETS FOR SNS FACILITY*

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Abstract

The Spallation Neutron Source (SNS) in process to be built in Oak Ridge Tennessee includes an accumulator ring with a circumference of 248 meters, an injection line and an extraction line. The machine is designed to accumulate 2E+14, 1.0GeV kinetic-energy protons in 1ms, via a charge exchange injection of H.

This paper describes the concept behind the design and fabrication of five types of air cooled corrector magnets built in 15 functions totaling 80 magnets to be used in the above project.

INTRODUCTION

The main effort was aimed toward an original design to deliver the required magnetic field with cost effective solutions and easy installation, survey and convenient maintenance.

The list of magnets designed by the above constraints is shown in Table 1.

Table 1. List of Corrector Magnets for SNS

Magnet ID	Magnetic Field, for 1.0/1.3 GeV	Current Amps.
16CD20	Dipole, Intgr. field: 7.4/8.8KG*cm	9.0/10.8
27CDM30	Dipole Intgr Field: 6.26/8.6KG*cm Skew Quad, Intgr Grad: 0.208/0.270KG Skew Sextupole Intgr. Grad: 0.005/0.007KG/cm	10.0/13.0 10.0/13.0 10.0/13.0
27CD30	Dipole Intgr. Field: 8.06 /10.08KG*cm	10.0/13.0
36CDM30	Dipole, Intgr. Field 7.20/9.0 KG*cm Skew Quad, Intgr Grd: 0.266/0.333KG	10.2/12.7 10.2/12.7
41CDM30	Dipole Intgr. Field 7.50/9.40KG*cm Skew Quad,Intgr. Gr: 0.241/0.301 KG	10./12/7 10.2/12.7

Figure 1 shows the magnets from Table 1, already built and in the process of being delivered to Oak Ridge.

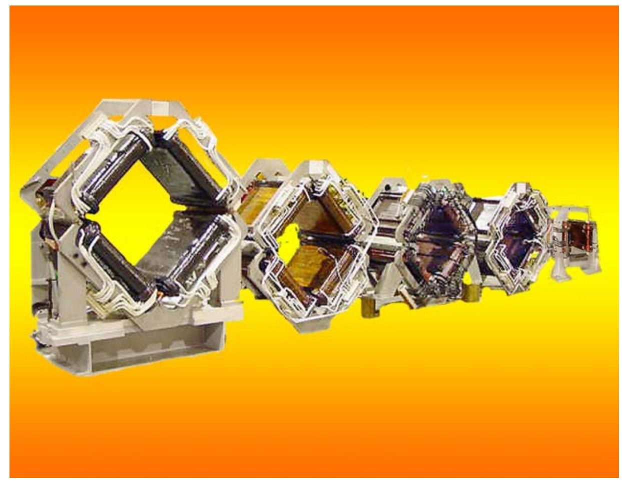

Figure 1. Actual picture of Corrector Magnets for SNS. (From left to right: 41CDM30, 36CDM30, 27CDM30, 27CD30, and 16CD20)

DIMENSIONAL MAGNETIC FIELD CALCULATIONS FOR THE 27CDM30 CORRECTOR MAGNET

The following 3Dimensional calculations performed for each of the corrector magnets provided information to be used in the mechanical design of the large aperture corrector magnets for the SNS accumulator ring.

a) The number of Amp-turns to produce the required dipole, sqew-quadrupole, and sqew-sextupole strength respectively.
b) The number of Amp-turns and the location of the “corrector coils” on the iron frame. These corrector coils (see figure 2) are required to minimize the sextupole strength produced by the main windings of the corrector dipole.
c) The number of Amp-turns of the coils which produce the sextupole corrector and also to determine the location of these coils on the iron.

The thickness of the iron core of the correctors was optimized to run well bellow the saturation when all

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corrector windings (dipole, quadrupole, and sextupole) were powered simultaneously at full strength). This condition of "non saturation" of the iron allowed us to make use of the superposition principle and perform the 3D calculations and optimization for each corrector (dipole, quadrupole, and sextupole) separately.

3D Dipole Calculations

Figure 2 shows the placement of the coils, which produce the dipole field of the corrector. The coils consist of three layers of copper wire, which cover almost each side of the magnet frame. In addition to these three layers of copper we wound a few more layers of copper wire (corrector coils) at each corner of the iron frame. These corrector coils are shown in Figure 2, and are connected in series with the coils, which produce the dipole field. Their purpose is to minimize the integrated sextupole field produced by the dipole coils. The number of Amp turns of the corrector coils has been determined by performing 3D magnetic field calculations.

The reason that the square frame of the iron has been rotated 45^0 is to generate the skew-quadrupole when the quadrupole coils are powered.

The integrated dipole field ($\int B_{dip}dz$), when the coils are powered at maximum is 8600 Gauss.cm. This is plotted in Figure 3 as a function of distance from the center of the magnet and along the beam direction.The plot shows the radial components of only two of the allowed multipoles (B_{sext}), and (B_{deca}), which are generated when the dipole coils are powered. The quantities (B_{sext}), and (B_{deca}), are defined in the expression:

$B_r(r_0,z)=B_{dip}\sin(\theta)+B_{sext}\sin(3\theta)+ B_{dec}\sin(3\theta)+\ldots$

(Where r_0=12.78 cm). The integrated strength of the sextupole component ($\int B_{sext}dz$) has been minimized with the help of the corrector coils mentioned earlier, and its integrated strength is 20 Gauss.cm at a radius r_0=12.78 cm. The integrated strength of the decapole multipole ($\int B_{decat}dz$) is 4 Gauss.cm. The integrated strength of the sextupole and decapole multipoles are well below the limit which will affect the dynamics of the beam.

Duodecapole components are the first allowed multipoles. The number of layers of the coil have been chosen to obtain the required sqew-quadrupole integrated strength ($\int B_{deca}dz$) which has been calculated to be 3500 Gauss.cm at a radius r_0=12.78 cm . When the sqew-sextupole corrector is powered at full current, the integrated strength of the first three allowed multipoles (12,20,28) pole is 30 Gauss.cm 10 Gauss.cm and 0.3 Gauss.cm respectively. Similar calculations were developed for the Skew-Quad and Sextupole.

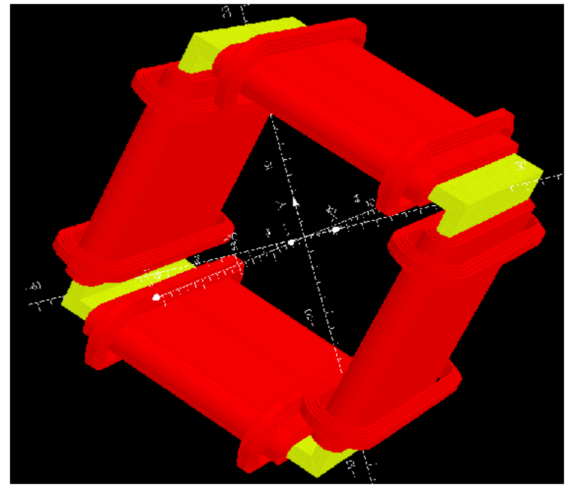

Figure 2. The windings of the dipole corrector.

The main windings cover almost each side of the iron core of the magnet and consist of three layers. The "corrector coils" which are powered in series with the dipole windings are placed symmetrically from each corner of the magnet.

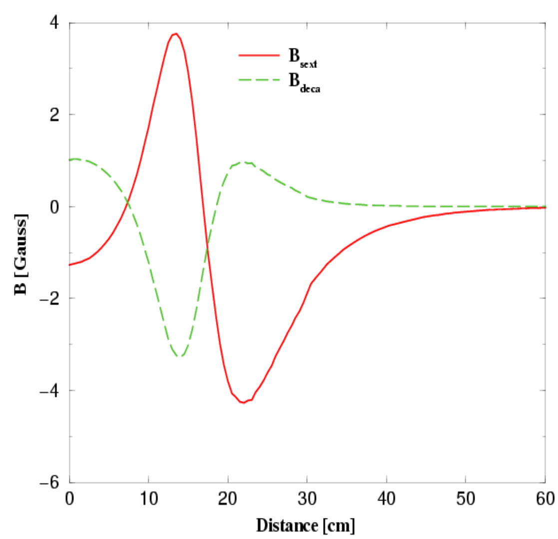

Figure 3: The calculated strength of the first two allowed multipoles (B_{sext}, and B_{deca}), of the dipole corrector magnet, plotted as a function of the distance from the center of the magnet and along the beam direction.

ENGINEERING CONCEPT AND CALCULATIONS

The entire family of magnets was designed with a standard approach as seen in Fig. 4.

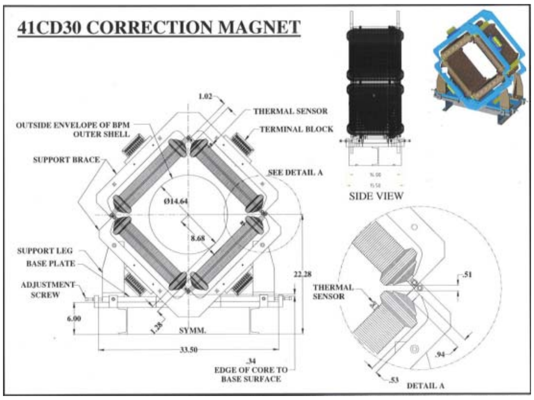

Fig. 4 Standard design of all corrector magnets

Based on aperture, length of magnet and magnetic field determined in the preceding chapter, the engineering part was developed as follows:

- Considering the number of ampere-turns the size of copper was determined (number of turns for dipole, quad or sextupole)
- All the cores and pole pieces were made of plain (non-laminated) steel 1006, because all the magnets are DC powered (no pulsed magnets included in this correctors category)
- The current density was kept under 100 Amps/cm²
- Calculations were performed using a finite element analysis program (ANSYS) to determine the stress, and maximum deflection under combinations of static loads and dynamic loads during transportation. Below in Fig. 5 is shown a typical result of stress analysis of a bracket, which holds the magnet true during split operations. Safety coefficient used for all the mechanical parts was 1.5.

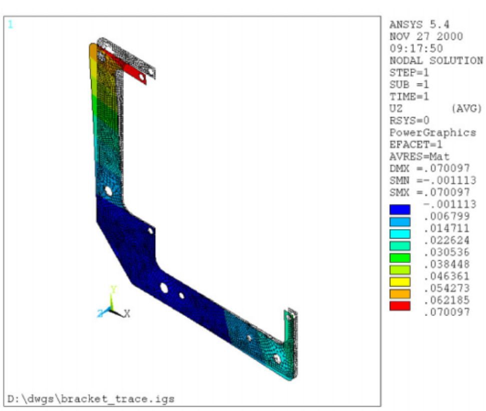

Fig. 5. Typical bracket deformed shape under maximum stress

ECONOMICAL CONSIDERATIONS

Based on actual prices of fabricated magnets we were able to plot the price variations as function of field values and weight.

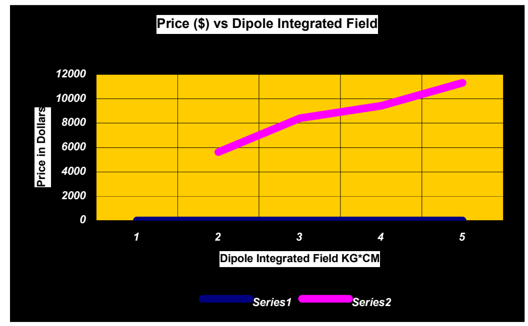

Fig.6 Price Variation Function of Dipole Field

Fig. 7 Price Variation Function of Magnet Weight

As expected there is almost a linear variation of the two parameters despite the fact that different companies fabricated each type of magnet. (in USA or abroad)

CONCLUSIONS

As stated at the beginning of the paper, the effort was oriented towards designing a family of new corrector magnets under the given conceptual constrains, and to achieve all the above under very tight budget. The authors consider the task fulfilled and are confident that the reliability of the products will be proven during the years to come.

ACKNOWLEDGEMENTS

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