B R O O K H A V E N   N A T I O N A L   L A B O R A T O R Y

MAGNET DIVISION NOTES

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Saturation a_1 Correction in SSC Dipoles

Ramesh Gupta

Both the calculations and measurements show a significant variation in a_1 (skew quadrupole) as a function of current beyond 6 tesla central field in SSC dipoles[1]. This is a systematic effect caused by the saturating iron in the yoke which is located asymmetrically with respect to the horizontal axis inside the magnetic cryostat vessel as shown in figure 1. This effect is in addition to the random a_1 caused by the coil construction errors[2]. The variation in a_1 with respect to current reflects that there is not sufficient iron in the yoke (shorter in radius by ~1cm) to contain the field lines at the design field of ~6.6 tesla. The effect is several time the allowed specification for the systematic tolerance of the skew quadrupole harmonic.

In SSC 40 mm Dipole the predicted a_1 saturation with POISSON is ~0.4 unit and PE2D is ~0.3 unit. The measured value in SSC 40 mm dipole is ~0.3 unit. The allowed specification for this harmonic is 0.04 unit. The situation is somewhat better in the case of 50 mm dipoles where the predicted a_1 saturation at 6500 Amp with the computer code POISSON is ~0.1 unit and with PE2D is ~0.2 unit. This is because of the fact that there is more space between the yoke and cryostat in 50 mm magnet as compare to what it was in 40 mm magnet. However, no comparison between the calculations and measurements can be made since no long 50 mm aperture dipole magnet has been built yet. The short magnets, built so far, have been tested without the cryostat vessel.

In this note we discuss several ways to reduce this systematic a_1 and to bring it within the allowed specification for this harmonic. It may be pointed out that for these calculations probably we are at the limit of what can be the expected accuracy of the computer calculations. Therefore, a detailed finalized design would require a confirmation with the measurements and one iteration may be required to achieve a proper compensation/cancellation of the a_1 saturation effect. It may be pointed out that at some field there may be a bit over compensation and as a result the change in a_1 as a function of current may change sign. The aim would be to reduce the maximum change in a_1 in the expected range of operation for the collider dipole with the compensation on.

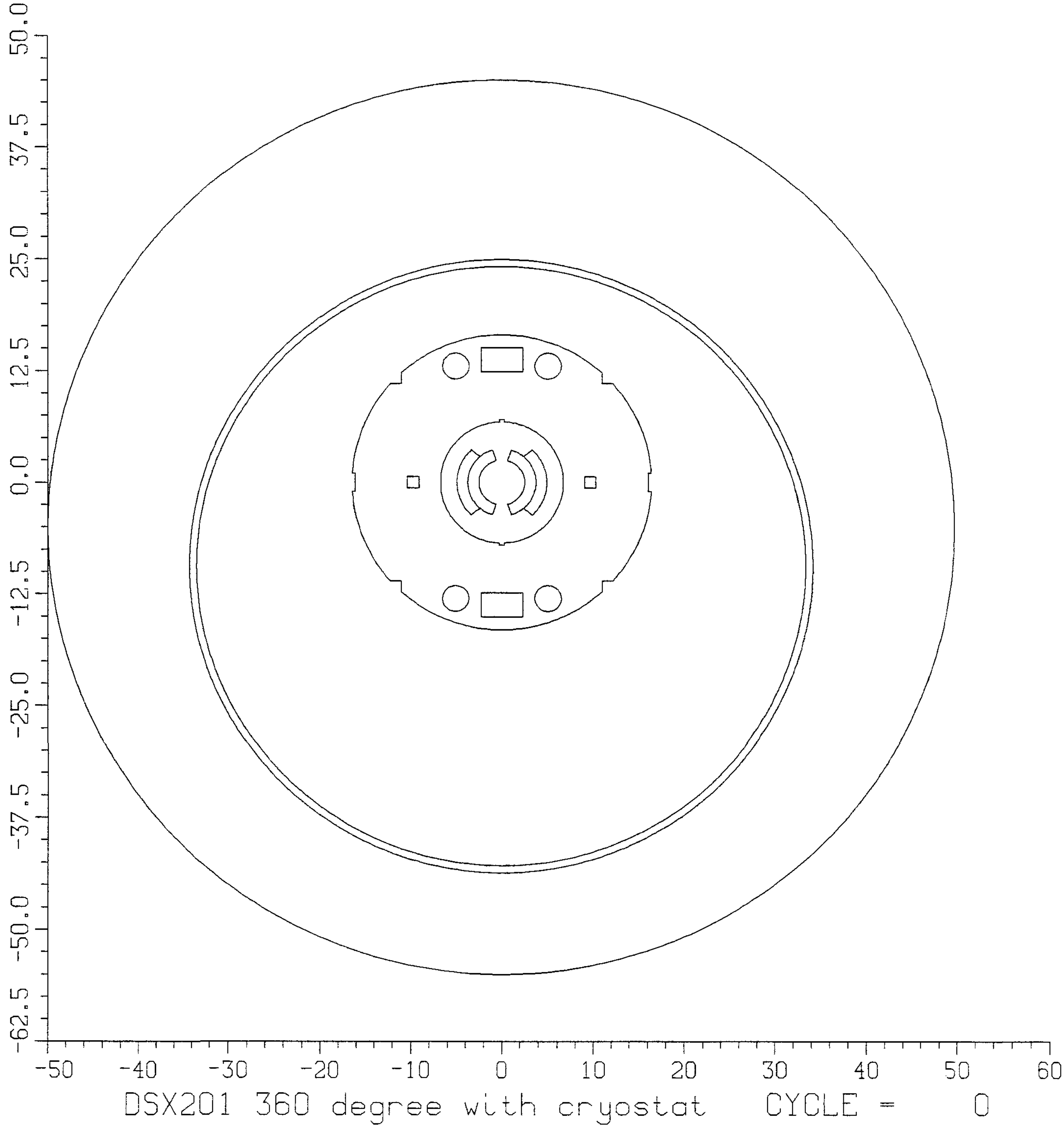

Figure 1: Off-centered yoke of SSC 50 mm magnet inside the cryostat.

The following schemes have been found adequate to reduce the a_1 saturation effect to an acceptable level. (Note that we have tried to cancel the a_1 as computed by POISSON code which has also been used in the calculations discussed below except where mentioned). The final choice of a particular scheme may depend on it's overall impact on the magnet production and the degree of cancellation desired at all values of central field.

1. Placing Conductors in a Computed Location in Buss Work

In reference 3, we discussed the a_1 produced by buss in SSC 40 mm dipole. We evaluated various configurations for the a_1 produced by the conductors at high field when the yoke iron starts saturating. A saturated iron yoke does not provide an adequate magnetic shielding the center of the magnet against the field lines produced by. As mentioned in reference 3, the horizontal configuration produces the maximum a_1 and the up-down minimum. The up-down configuration was, therefore, preferred for the SSC magnets. However, it has been found that with a proper spacing between the two conductors in the buss, the a_1 produced by the proximity of the cryostat wall can be compensated by the a_1 produced by buss. POISSON calculations show that in the horizontal configuration case if the cable is placed 5 mm off the vertical axis, the net a_1 in the magnet stays within the specified tolerance of 0.04 unit. The direction of the current in the buss cable should be opposite to the direction of the current in the coil below it on the same side. a_1 caused by the buss alone is $\sim$ 0.1 unit at 6500 A. PE2D calculations by Kahn at BNL confirms this number. (Snitchler calculations at SSCL, also done with PE2D, however, predict this number to be 0.6 unit – the differences may be due to the way the problem is solved with PE2D and is currently being investigated). The scheme also works in the vertical configuration (mechanically this might be considered as rotated up-down configuration), as long as the midpoint of the cable is the same as it was in the horizontal case. A tuning of a_1 cancellation can be obtained by changing the spacing between the conductor in the buss work.

2. Using a few Non-magnetic Steel Laminations in Upper Yoke-half

If the number of magnetic laminations are different between the top and bottom half of the magnet, a skew quadrupole term is created. A practical way to implement this in a magnet would be that some of the low carbon steel (magnetic) laminations be replaced by the stainless steel (non-magnetic) laminations in the upper yoke-half. If the number of non-magnetic laminations is a small fraction of magnetic laminations, the situation can be simulated in a computer program by using the difference in packing factor in the top and bottom half of the problem. POISSON calculations show that $\sim 0.1\%$ difference in packing factor is adequate to bring the net a_1 within the specified tolerance of 0.04 unit. Since the thickness of lamination is 16 GA (0.0598 inch), it means that in a long magnet one would need to change only 9 laminations from magnetic to non-magnetic in the top half. This scheme has easy tunability – one would simply change the number of stainless steel laminations.

3. Placing Extra Magnetic Steel at the Bottom of Yoke

Since the saturation a_1 is caused by the proximity of cryostat wall at the top half of the magnet, a natural solution to this problem would be to put some extra iron on the opposite side of it. We examined several configuration and ways to put this extra iron at the bottom half of this magnet. POISSON calculations show that 1 mm thick iron strip from 180 degree to 360 degree will be adequate to produce the required compensation. If the strip is put from 225 degree to 315 degree (width = 90 degree) the thickness required would be 1 cm. This scheme also has easy tunability – one would simply change the width or thickness (or both) of the iron strip.

References

1. S. Kahn and P. Wanderer in February 91 MSIM at SSCL, Dallas.

2. R. Gupta, "Random a_1 Correction in SSC Dipoles", Magnet Division Note No. 388-1 (SSC-MD-268), July 26, 1991.

3. R. Gupta, "Effect of the Position of Buss Conduit on Field Harmonics at the Center of a SSC Dipole", Magnet Division Note No. 326-1 (SSC-MD-232).