MAGNET DIVISION NOTES

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Magnetic Field implications of using the low carbon magnet steel in the lamination for He Bypass Channel

Ramesh Gupta

Introduction

It has been proposed that the low carbon steel (magnetic) be used in the lamination for He bypass channel instead of using stainless steel (non-magnetic) as being done presently. In this note we examine the effect of it on the field harmonics of SSC Dipole, both at low field and at high field.

The bypass channel lamination is $0.12''$ thick and is placed at an interval of $12''$. However it is not placed at the same location in the magnet at above the midplane and below the midplane. As shown in Fig 1, the relative distance in these two sets of laminations is $6''$. The geometry of the bypass lamination itself is shown in Fig 2. The geometry of coil and of regular lamination is same as the one described in reference 1.

Setting up 2-D models

This problem basically requires a 3-D model. However, the change in field harmonics, in going from non-magnetic to magnetic bypass lamination, can be estimated by converting this 3-D problem to 2-D one with some reasonable assumptions. We use 3 models to adopt this problem for POISSON, a 2-D code. All models give the results which show that the change in field harmonics would be relatively small. It is, therefore, concluded that there is no need to do a more rigorous calculation based on the 3-D model.

First we refer to the up-down asymmetry caused by the fact that the bypass laminations are not placed in the same location above the midplane and below the midplane. It can be assumed that to first order, their integrated effect will be as if the up-down symmetry was present. Since the number, size and shape of the bypass laminations in up and down plane is same and they account for only 1% of total yoke thickness, it is a reasonable assumption. Since there is a perfect left-right symmetry, we need to model only $\frac{1}{4}$ of the magnet.

We try three models to integrate the effect of the magnetic bypass lamination in the regular lamination. Let us recall that the bypass lamination has a width of $0.12''$ and the combined width of bypass and regular lamination is $12''$ in each period. This means that in the total yoke mass, 1% contribution comes from the bypass lamination and 99% from the regular lamination. We can take this into account in a single lamination using the packing factor approach. Before, in case of non-magnetic bypass lamination the packing factor used was 99% of what it actually is in the material. Now we use 100% packing factor in the iron for material number 3 (MAT=3), except at the place where the cutout for He bypass channel is present; at the cutout we still use 99% packing factor since no extra magnetic material is added here. This model is shown in Fig 3 and the cutout is shown having the material number 4 (MAT=4) with 99% packing factor.

The inherent assumption of a 2-D model is that the field lines do not go out in the third dimension. However, in a real magnet they will bulge out at the cutout in the bypass lamination due to increased reluctance at this place. In the above 2-D model we have averaged this change in reluctance with the packing factor approach over the width of $12''$, the periodic length of the structure. However, one can argue that the depth of bulge in the field line should be considered about equal to the width of the cutout, which is 1 inch. That means that we should change packing factor in the cutout only for this 1 inch width of the yoke and the rest $11''$ would be the regular lamination with a packing factor of 100% . The new field harmonics then will come from the weighted average of these two sets of laminations. Since the bypass lamination thickness is $0.12''$, the packing factor of the $1''$ long yoke at the cutout (MAT=4) will be $\frac{1}{1+0.12} \simeq \frac{8}{9}$ of what it is in the rest of the iron. In our second model this lamination contribute for the 8.4% and the regular lamination contribute 91.6% for the field harmonics.

In our third model we add the effects of the two laminations the way physically they are. That is 99% contribution comes from the regular lamination (having packing factor of 100% everywhere) and 1% from the lamination with physical cutout (i.e, use MAT=1 of air is used at the cutout instead of using MAT=4 of iron), as shown in Fig 2. It should be pointed out that this cutout would strongly force field lines radially out, whereas in reality the field lines simply bulge out in the third dimension. Because of this incorrect representation in the third model, the saturation effects get over emphasized. Even at low fields, due to the inability of implementing a correct boundary condition in 2-D at the cutout, the field harmonics get changed by a large amount.

Calculations and Results

In Table 1, we give the results of calculations for regular lamination with 100% packing factor. In table 2, the results for the same lamination are given for 99%packing factor. In table 3, we give the results of calculations when packing factor of 99% was used in the cutout for model 1. In table 4, the packing factor of $\frac{100*8}{9}$ % is used in the cutout for model 2. In table 5, we summarise the reults of calculations when the air was specified in the cutout for model 3.

The harmonics for model 1 are those given in table 3. The harmonics for model 2 are computed by taking 8.4% contribution from table 4 and 91.6% from table 1. The harmonics for model 3 are computed by taking 1% contribution from table 5 and 99% from table 1. When the bypass lamination was not magnetic the harmonics were those in table 2; we call this the original case. In table 6 we list these results. We compute the change in harmonics with respect to the original case to determine the impact of using the low carbon magnet steel for bypass channel lamination instead of using non-magnetic steel. The computed change change in harmonics for the three models is given in table 7.

In conclusion, we say that the low carbon magnet steel can be used for the He bypass channel lamination from the field harmonics point of view. It does produce some change but the field harmonics still remain well within the specified tolerances.

References

1. Ramesh Gupta, "New Yoke Design for 4 cm SSC Dipole to Reduce b_2 saturation to $<$ 0.4 unit", Magnet Division Note No. 326-1 (SSC-MD-233), June 21, 1989.

Table 1: POISSON Run for Regular Lamination with 100% Packing Factor.

B_o Tesla	I Amp	T.F. T/kA	b_2' 10^{-4}	b_4' 10^{-4}	b_6' 10^{-4}	b_8' 10^{-4}	b_{10}' 10^{-4}
0.20293	194.7	1.04225	-0.0896	-0.4187	-0.0021	0.0278	0.0852
6.61112	6490	1.01866	-0.3181	-0.4853	-0.0040	0.0284	0.0872

Table 2: POISSON Run for Regular Lamination with 99% Packing Factor.

B_o Tesla	I Amp	T.F. T/kA	b_2' 10^{-4}	b_4' 10^{-4}	b_6' 10^{-4}	b_8' 10^{-4}	b_{10}' 10^{-4}
0.20293	194.7	1.04225	-0.0900	-0.4188	-0.0019	0.0278	0.0852
6.60233	6490	1.01731	-0.3731	-0.4859	-0.0044	0.0284	0.0873

Table 3: POISSON Run for New Bypass Lamination with 99% Packing Factor at the cutout (MAT=4) for Model 1.

B_o *Tesla*	I *Amp*	*T.F.* T/kA	b_2' 10^{-4}	b_4' 10^{-4}	b_6' 10^{-4}	b_8' 10^{-4}	b_{10}' 10^{-4}
0.20293	194.7	1.04225	-0.0893	-0.4185	-0.0019	0.0278	0.0852
6.60903	6490	1.01834	-0.2614	-0.4834	-0.0046	0.0283	0.0872

Table 4: POISSON Run for New Bypass Lamination with $\frac{100*8}{9}$ % Packing Factor at the cutout (MAT=4) for Model 2.

B_o *Tesla*	I *Amp*	*T.F.* T/kA	b_2' 10^{-4}	b_4' 10^{-4}	b_6' 10^{-4}	b_8' 10^{-4}	b_{10}' 10^{-4}
0.20293	194.7	1.04225	-0.0876	-0.4182	-0.0020	0.0278	0.0852
6.58972	6490	1.01537	0.6442	-0.4228	-0.0064	0.0284	0.0875

Table 5: POISSON Run for New Bypass Lamination with air used at the cutout for Model 3.

B_o *Tesla*	I *Amp*	*T.F.* T/kA	b_2' 10^{-4}	b_4' 10^{-4}	b_6' 10^{-4}	b_8' 10^{-4}	b_{10}' 10^{-4}
0.19967	194.7	1.025537	1.7057	0.2045	-0.0322	0.0286	0.0866
6.36654	6490	0.980977	13.399	0.0614	-0.0278	0.0295	0.0907

Table 6: Computed field harmonics for three models when low carbon magnet steel is used for bypass lamination. The original case, for non-magnetic carbon steel is also listed here for the reference.

Case	I Amp	$T.F.$ T/kA	b_2' 10^{-4}	b_4' 10^{-4}	b_6' 10^{-4}	b_8' 10^{-4}	b_{10}' 10^{-4}
Method 1	194.7	1.04225	-0.0893	-0.4185	-0.0019	0.0278	0.0852
Method 2	194.7	1.04225	-0.0894	-0.4187	-0.0021	0.0278	0.0852
Method 3	194.7	1.04208	-0.0716	-0.4125	-0.0024	0.0278	0.0852
Original	194.7	1.04225	-0.0900	-0.4188	-0.0019	0.0278	0.0852
Method 1	6490	1.01834	-0.2614	-0.4834	-0.0046	0.0283	0.0872
Method 2	6490	1.01836	-0.2315	-0.4797	-0.0042	0.0284	0.0872
Method 3	6490	1.01828	-0.1809	-0.4798	-0.0042	0.0284	0.0872
Original	6490	1.01731	-0.3731	-0.4859	-0.0044	0.0284	0.0873

Table 7: The change in field harmonics if bypass channel lamination is made of magnetic steel instead of non-magnetic. These results are computed as (magnetic - nonmagnetic), i.e., (new-old).

Method No.	I Amp	$\delta\,(T.F.)$ % Change	$\delta b_2'$ 10^{-4}	$\delta b_4'$ 10^{-4}	$\delta b_6'$ 10^{-4}	$\delta b_8'$ 10^{-4}	$\delta b_{10}'$ 10^{-4}
1	194.7	0.000	0.001	0.000	0.000	0.000	0.000
2	194.7	0.000	0.001	0.000	0.000	0.000	0.000
3	194.7	0.016	0.018	0.006	0.000	0.000	0.000
1	6490	0.101	0.112	0.003	0.000	0.000	0.000
2	6490	0.103	0.142	0.006	0.000	0.000	0.000
3	6490	0.095	0.192	0.006	0.000	0.000	0.000

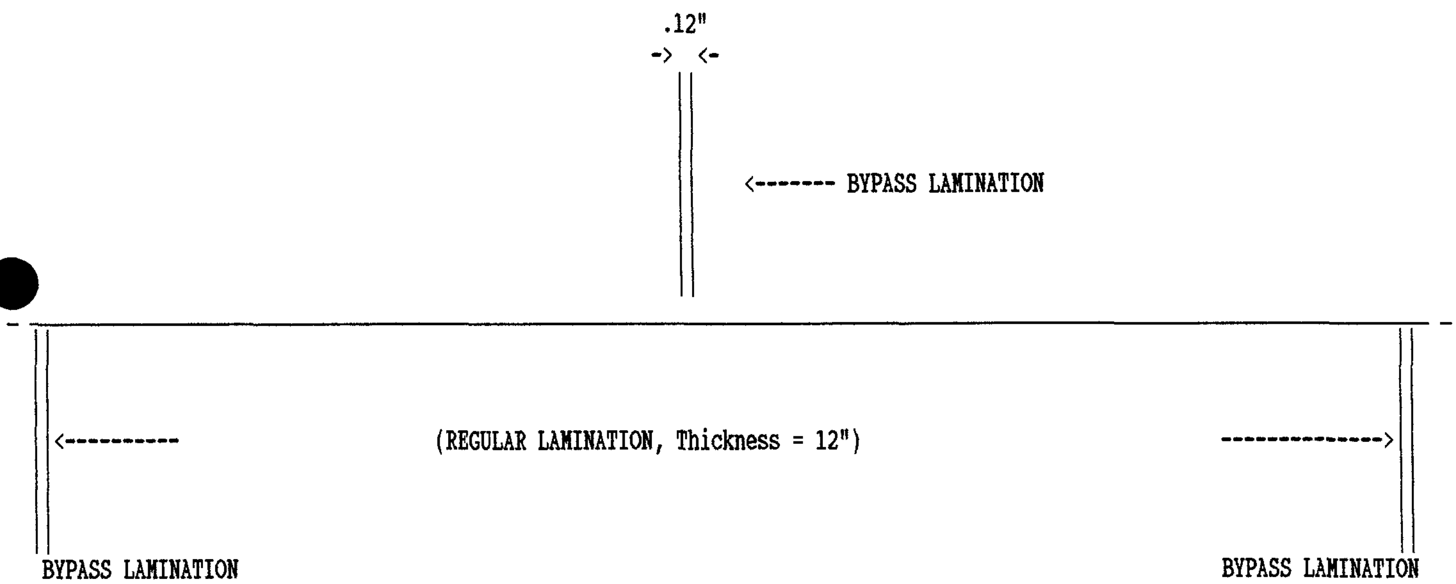

FIG 1. The placement of the He bypass channel lamination across the magnet.

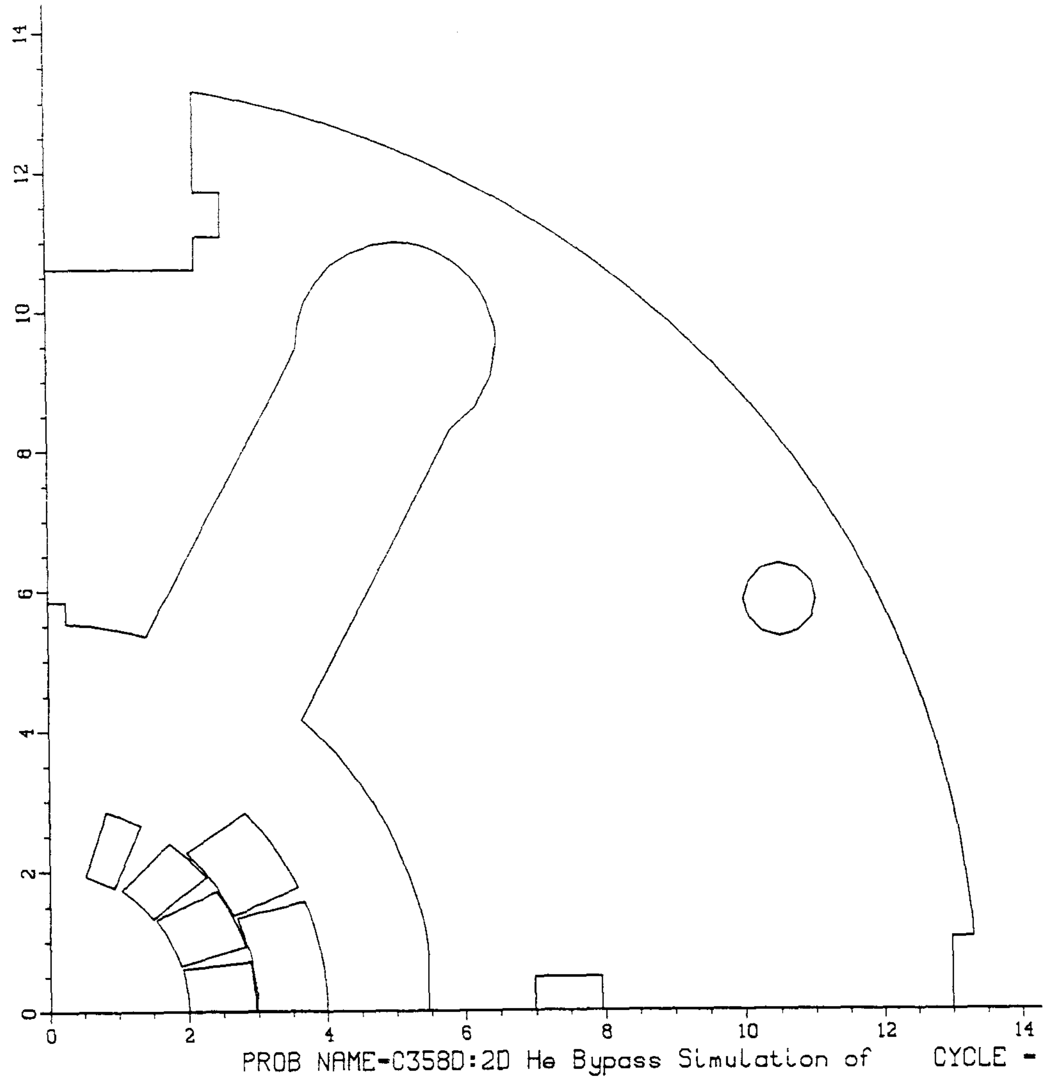

Fig 2. The Geometry of the He bypass lamination.

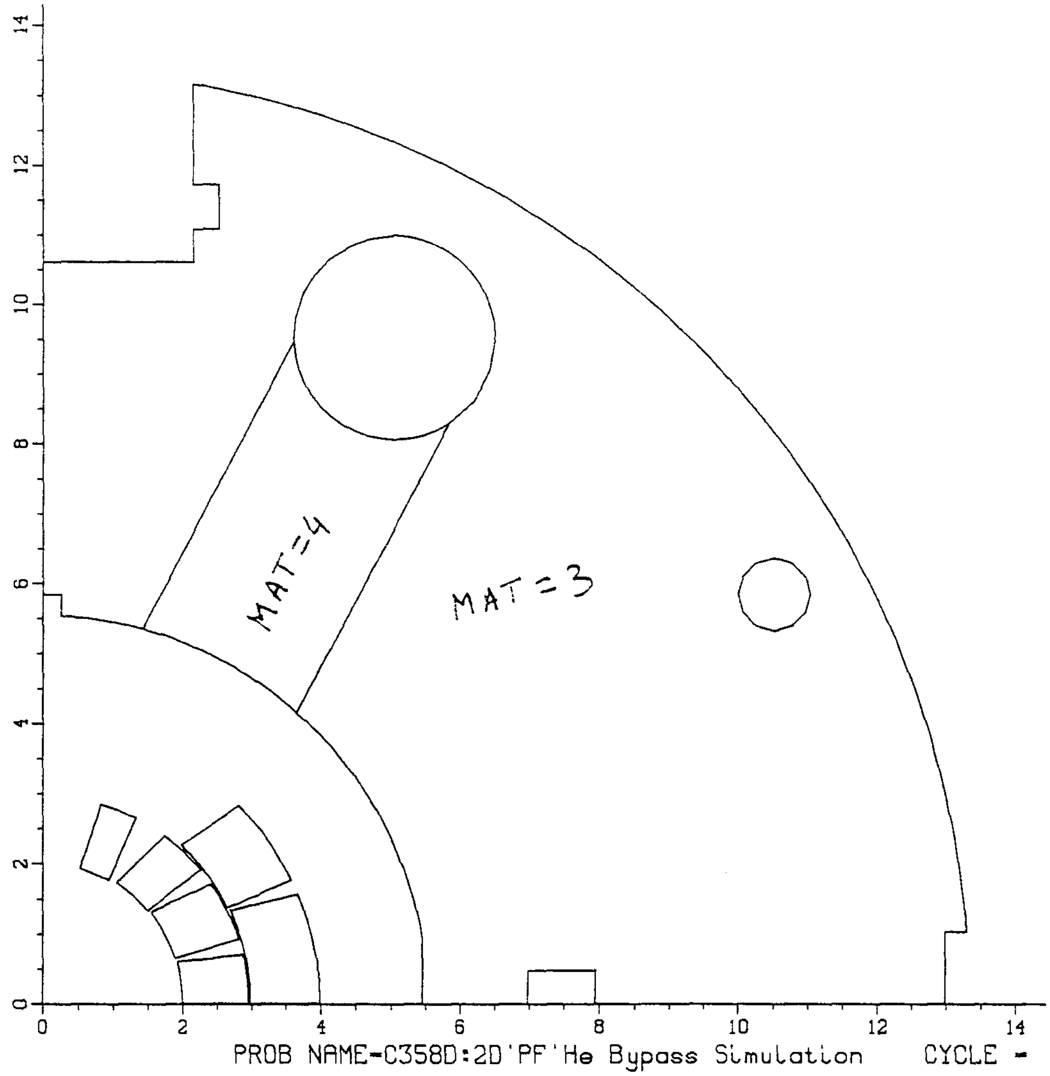

Fig 3. The use of MAT=4 at the cutout to describe the iron of differnt packing factor then the one (MAT=3) used in the rest of the iron.