MAGNETIC FORCES ON THE LAMINATIONS OF THE BOOSTER DIPOLE

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In this note we report the results of calculations for the magnetic forces on the iron laminations of the booster dipole magnet. The booster magnet is made up of several blocks with each block containing several laminations either glued or stacked. The thickness of each lamination is 25 mil. At each end of each block there are 40 laminations glued together which are individually modeled comprising a section of 1" thick glued laminations. For the purpose of computing the forces in region II of Fig 1, 60 laminations stacked together are individually modeled, making a section one and a half inch thick of stacked laminations. We compute the forces on these individual laminations and also on the group of 1" thick section of glued laminations as a whole. The sketch of the top part of the magnet in the vertical plane containing the beam axis is shown in Fig 1 - the coils and the full upward extent of the iron is not shown in this figure.

The model on the computer code POISSON is shown in Fig 2. The POISSON is a 2-D code and basically we have a 3-D problem. However, we use the following method to represent this in a 2-D model. We first model the iron pole in the vertical plane containing the beam axis. On the upper boundary we use the Neumann boundary conditions (field perpendicular). This provides the return path for the magnetic flux. We place the coil far away from the region where the forces are to be computed. This minimizes the effect of the coil field - the only purpose of the coil in this model is to generate the desired central field.

An important consideration in setting up the mesh is to be able to model each lamination separately - at least at the place where the force on the individual laminations is to be computed. This requires a very high mesh density at that place. Since the laminations are rectangular, the job greatly simplifies when the right triangles are used for creating the mesh. Even after using a low mesh density in the region where the force on the individual lamination is not to be computed, we need over 12,000 nodes to set up this model.

The code POISSON computes the vector potential and the magnetic field. The force calculation is done in two ways by using these values at appropriate places. One way is by using these values in an analytic formula and second way is by using them (the values are read automatically) in the FORCE part of the POISSON Group Codes. Both methods are found to be consistent to each other. We also tried to use the energy difference method to verify these computations. However, the energy difference was so small that due to computer round off errors the method was not found reliable.

Results and Discussion

For the purpose of this discussion we have divided the magnet in sections I, II, III and IV (Please see Fig 1 for the definition of these sections). In the one magnet constructed for the booster, it has been found that the section III had a 10 mil downward displacement. We designate this to be case B, whereas, case A is as the magnet should have been, i.e. with no displacement. We also compute the forces on the individual laminations in section II, III and IV. The following laminations are of particular interest and the forces on them are discussed below :

1. Last lamination in section II (at the boundary of section III). The force on this lamination is found to be 0.153 PDS/INCH. The force on the other laminations in this section is found to be slightly higher, it increase very slowly as one goes towards section I.

2. Last lamination in section III, just before the air gap which is located between the section III and section IV. In the present magnet the air gap is 125 mil but it is proposed that it can be 0.5 mm. The force on this last lamination is found to be 5.127 PDS/INCH with 125 mil gap and 2.133 PDS/INCH with 0.5 mm gap. The force on the other laminations in the same section is found to be very small with either size of gap.

3. First lamination in the section IV just after the air gap. The force on this lamination is found to be -4.792 PDS/INCH with 125 mil air gap and -2.359 PDS/INCH with 0.5 mm gap. The force on the other laminations in this section is found to be very small with either size of gap.

The relatively large forces on the single lamination on the either side of the gap do not decrease very rapidly as the gap decreases. This suggests that if the glue fails, it would be desirable to have no gap.

The force on section I is found to be -38.8 PDS/INCH. For 125 mil air gap, the force on section III is 2.124 PDS/INCH and on section IV is -5.505 PDS/INCH. This force is due to two fringe fields. First, due to the effect of the end of iron (at section I) and second, due to the air gap between section III and section IV. First source tend to produce the forces in the same direction on these two sections and the second source in the opposite direction. The opposite sign in the values of forces in section III and IV indicates that for 125 mil gap the second source is more dominant. For 0.5 mm air gap the force on section III is -4.302 PDS/INCH and on section IV is -3.259 PDS/INCH. The same sign in the values of forces indicates that for 0.5 mm gap, it is the first source which is more dominant in determining the overall force. This can be also be seen from Fig 4 where we have plotted the field lines in the vicinity of that air gap. However, the air gap still determines the local influence, i.e., the forces on the adjacent lamination on the either side of the gap. As outlined earlier the force on the last lamination of section III and on the first lamination of section IV have opposite sign for both values (125 mil and 0.5 mm) of the gap.

We also wanted to observe that how the force is distributed across the height of the laminations. It is found that the force on the individual laminations in section III and in section IV is localized almost all at the bottom tip of the laminations. For the distribution of the force at the other places, please refer to Fig 3 in which the numberes 1, 2 and 3 refer to forces on the three heights of the same lamination. Note that there is little difference between cases A and B; this suggests that the forces are mainly due to the proximity of the ends.

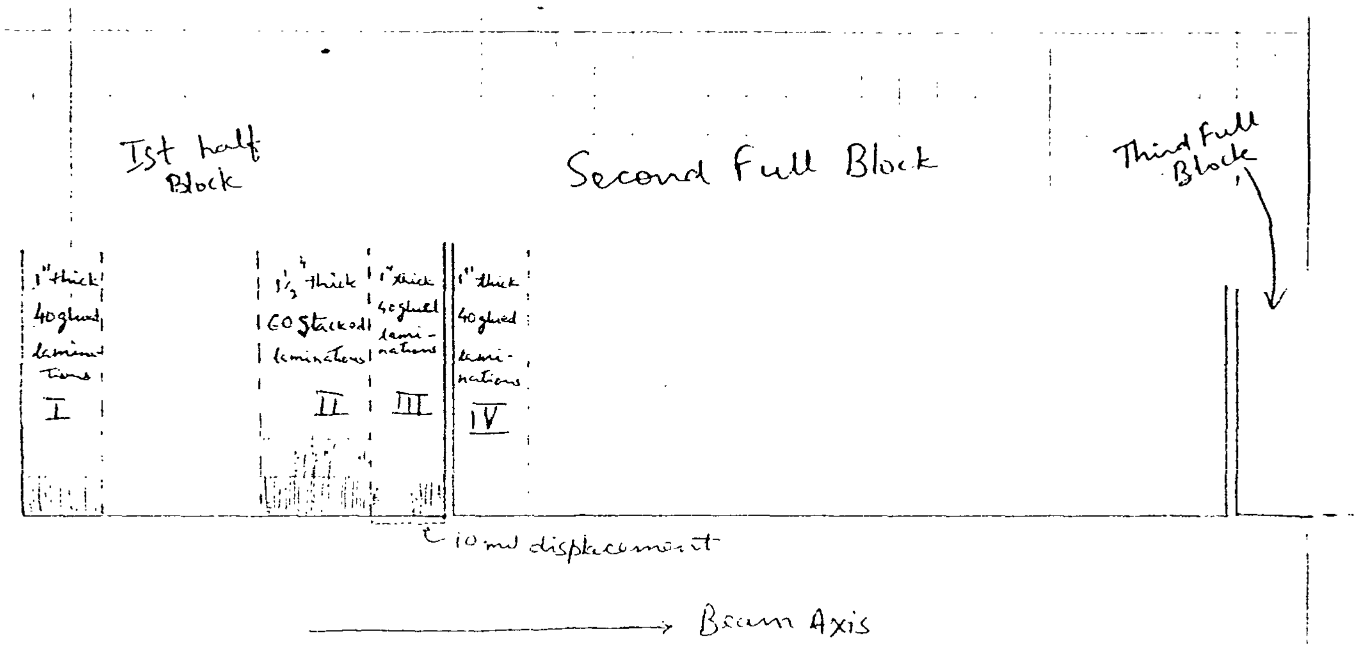


Fig 1. Sketch of the top part of the Booster magnet

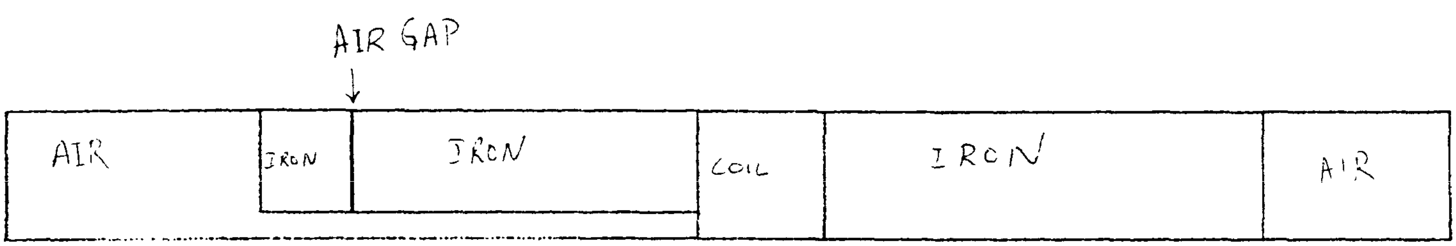
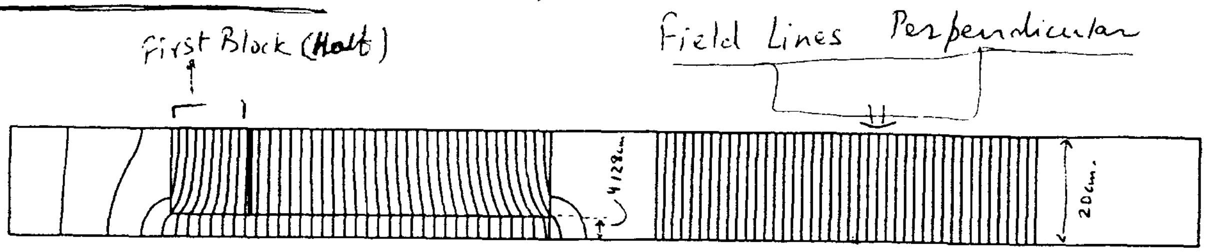


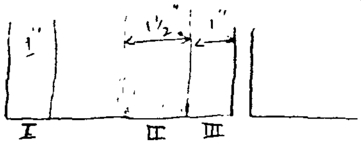
Fig 2. The model on the computer code POISSON

Force Calculation (at 11·8 KG)



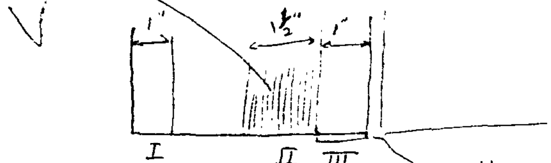
(half gap height = 4·128 cm)

CASE A



CASE B

60 Laminations – 25 mil each



LAMINATION HEIGHT (cm.) (On which the force is calculated)		Case A: Force (PDS/INCH) on the innermost Lamination†	Case B: Force (PDS/INCH) on the innermost lamination†
5·107 – ~~~~4·128 = ·979	1	−0·063	−0·048
10 – 4·128 = 5·872	2	−0·143	−0·112
20 – 4·128 15·872	3	−0·153	−0·122

more like the surface force

Force on I (1" block)

	Case A	Case B
1	−39·1	−36·4
2	−37·9	−36·1
3	−38·8	−36·7

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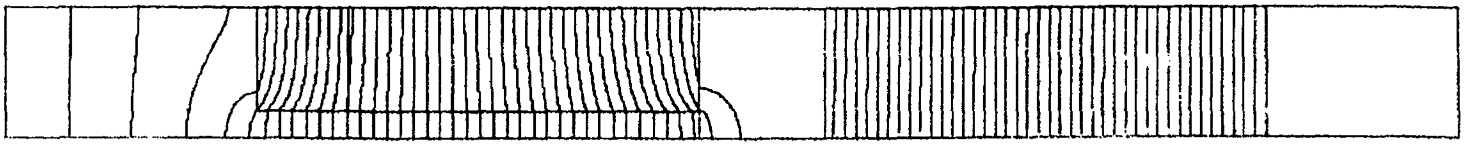
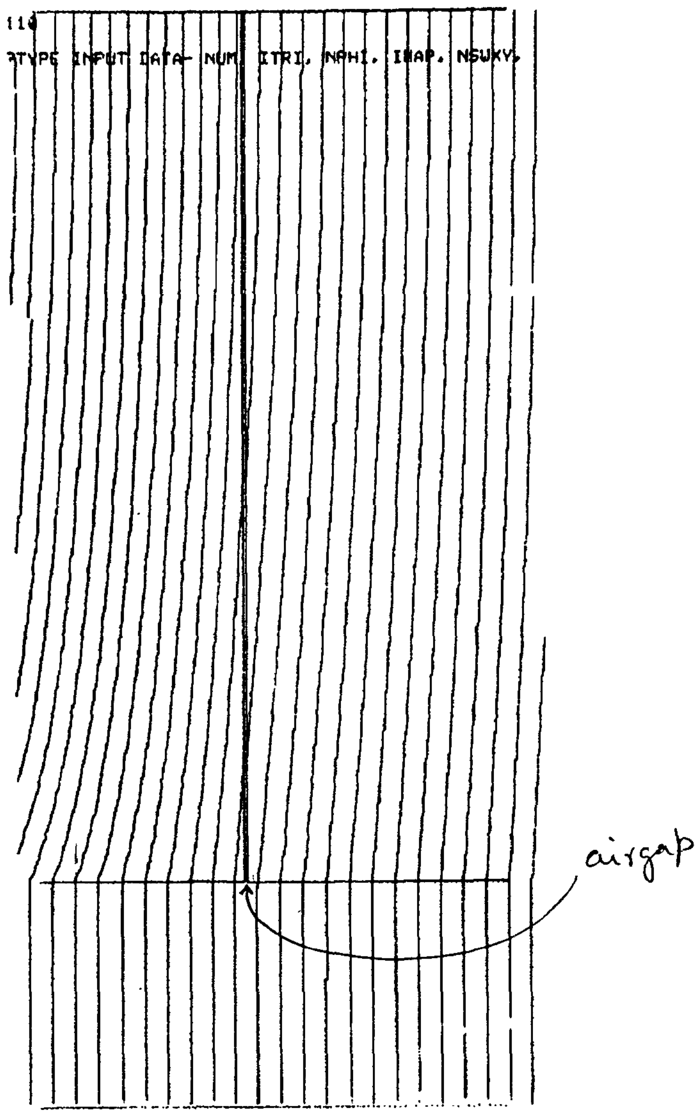
† Innermost lamination means the last lamination in II, at the boundary of III.

FIG 3



PROB. NAME = New Model for Force Calculation CYCLE = 9

Fig 4(a). Field lines in the complete magnet.



PROB. NAME = New Model for Force Calculation CYCLE = 9

Fig 4 (b). Field lines in the vicinity of air gap.