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Subject A final design for a 6-in. x-y steerer for the DRAGON facility		

1. Introduction

A previous note[1)] reported on the design study of a 6-in. x-y steering magnet for the DRAGON facility. This report presents a final design for such a magnet. As such, this note should be considered as an addendum to ref[1)].

2. The final design for the 6-in. x-y steering magnet for the DRAGON facility

Figure 1 shows the final proposed design for the 6-in. x-y steering magnet for the DRAGON facility. For comparison, the design proposed in ref[1)] is shown as figure 2. Other than an increase in the width of the 'pole' from the 1.60 in. value of ref[1)] to 3.10 in. here, the designs are seen to be identical. The coil shape and size are unchanged.

For completeness we also reproduce here as table 1, table 2 of ref[1)]. No changes have been made in the data of the table despite the small increase in the weight of the yoke arising from increased pole width because the amount of iron required to fabricate the yoke is unchanged.

3. Results of POISSON runs for the final design

POISSON[2)] runs were made for the final design to verify that there were no significant differences between this design and that reported in ref[1)]. Runs were made with the horizontal coils *only* powered at 5,000 A-t each—a value corresponding to nominal full power—and with both the horizontal *and* vertical coils powered at that value. We consider the results of these run separately.

3.1 Horizontal coils powered only powered at 5,000 A-t

Figure 3-a shows the calculated results with the horizontal coils powered. Figure 3-b shows the predicted variation of B_y as a function of distance y from the midplane. The results shown in this figure are to be compared with those shown in figure 11 of ref[1)]. The latter is reproduced here as figure 4.

Comparison of figures 3 and 4 indicates that the required field uniformity is maintained in the most recent design. Indeed, there is little to choose between the two designs. The field uniformity of the present design is, perhaps, slightly better than that of ref[1)] over the region $|x| \leq 1.5$ in. and slightly poorer over the region $|x| \leq 2.5$ in.

From this data we conclude that the increase of the pole-width causes no problems as far as field uniformity is concerned.

3.2 All coils powered at 5,000 A-t

Figure 5-a shows the predicted $|B_x|$ contours and figure 5-b shows the predicted variation of that field as a function of distance from the midplane for values of x of -0.5 in., 0 in. and $+0.5$ in. Similar results for B_y are shown in figure 6. Comparison of these figures with figure 4 shows that powering both horizontal and vertical coils (in this case, nominally to full power) results in a different symmetry of the predicted field distributions. We note, however, that the contours shown for $|B_x|$ are identical to those shown for B_y rotated 90°. That this is arises because the vertical and horizontal coils are powered equally.

With the coils powered for steering in either the horizontal plane *or* the vertical plane, figure 3 shows that the expected field distribution is symmetric about each of the horizontal and vertical axes. On the other hand, when vertical and horizontal coils are *equally* powered, figures 5 and 6 indicate that that symmetry is changed to one of reflected symmetry about axes at 45° angles with respect to the coordinate axes. This is clearly shown in figures 5-b and 6-b. It is seen that the predicted field profile one-half inch below the midplane has a 'bump' at positive y and x, respectively. The profile predicted one-half inch above the midplane is identical *except* that it is mirrored about the symmetry axes x and y respectively.

Figure 7 shows the same effect in the variation of B_y at other distances (y) from the midplane. The variation of $\mid B_x \mid$ is not shown; it is assumed that will be as predicted for B_y (with the appropriate changes in notation).

This variation of B_y at distances from the midplane is shown in another fashion in figure 8. The upper portion shows the *difference* between B_y at a distance y from the midplane and that on the midplane for the case in which only the horizontal coils are powered. The lower portion shows those differences when the horizontal and vertical coils are powered equally. Differences for negative values of y—that is, below the midplane—are found by reflecting figure 8-b about $x = 0$. From the upper figure it is seen that the maximum deviation from the midplane field with only the horizontal coils powered is approximately 10 Gauss ($\approx$3%) for $\mid x \mid \leq 2.2$ in., provided that the beam is within $\pm$2 in. of the midplane. With all coils equally powered this 10 Gauss difference is maintained over the region -1.9 in. $\leq x \leq +2.6$ in. for that portion of the beam that is no more than 2 in. above the midplane. For that portion of the beam that is no more than 2 in. below the midplane, the 10 Gauss difference is maintained over the region -2.6 in. $\leq x \leq +1.9$ in.

4. Coil configuration

Finally, we consider one question about the coil configuration: Is is necessary to wind the coil with a 'hole' at the midpoint? To answer this a POISSON run was made with the hole removed—that is, with 30 turns in each of the first and second layers of the coil—and with no other changes. Shown in figure 9-a are the predicted B_y contours for this case with *all* coils equally powered at 5,000 A-t. Comparison of figures 6-a and 9-a clearly shows the effect of the removal of the hole. More dramatic is a comparison of figures 6-b and 9-b. The field uniformity shown in the former is completely lost in the latter. There is no question that the hole in the coil is necessary in this application.

5. Discussion

This report has presented a final design for a 6-in. steering magnet for the DRAGON facility. Only the yoke shape given in ref[1] has been changed with a view to a simplification of its construction.

It has also been shown that an asymmetry is to be expected between the steering of particles above the median plane and those below it when the magnet is operated in an x-y steering mode. This asymmetry is predicted to be small (approximately $\pm$3%) provided that the beam is kept within two-thirds of the full aperture. However, before steering magnets are constructed according to this design, the effects of such an asymmetry should be studied.

Given the results of the experiment, it is felt that the coil shape proposed here and in ref[1] is necessary for the steering magnet and its required uniformity.

References

1. G. M. Stinson, *A simple 6-in. steerer for the* DRAGON *facility*, TRIUMF Report TRI-DNA-98-7, December, 1998.
2. M. T. Menzel and H. K. Stokes, *User's Guide for the POISSON/SUPERFISH Group of Codes*, Los Alamos National Laboratory Report LA-UR-87-115, January, 1987.

Table 1 (Table 2 of ref[1])

Design parameters of the DRAGON $x - y$ steering magnet

Top yoke:	Thickness (max.)	1.25 in.
	Width	9.90 in.
	Length	5.00 in.
	Weight	14.94 lb.
Side yoke:	Thickness (max.)	1.25 in.
	Width	7.90 in.
	Length	5.00 in.
	Weight	12.11 lb.
Coil:	Conductor	0.162 in. square
	Length per coil	1,225.00 in.
	Weight per coil	7.63 lb
	Resistance (hot) per coil	0.0481 Ω
	Maximum current per coil	100.0 A
	Voltage drop per coil	4.81 V
	Power dissipation per coil	0.481 kW
	Coolant flow rate per coil	2.30 ft/sec
	Pressure drop per coil	28.20 psi
Overall magnet:	Iron weight per magnet	55.00 lb
	Copper weight per magnet (4 coils)	35.00 lb
	Total weight per magnet (4 coils)	90.00 lb
Power supply:	Maximum current	100.0 A
	Minimum voltage (2 coils in series)	11.0 V
	Minimum power (2 coils in series)	1.1 kW

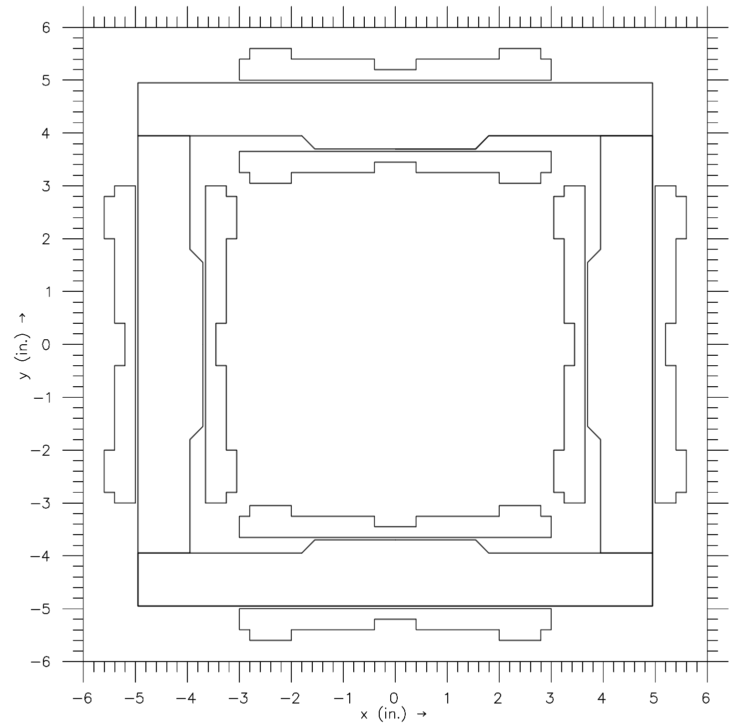

Fig. 1-a. Cross-section of the proposed steering magnet.

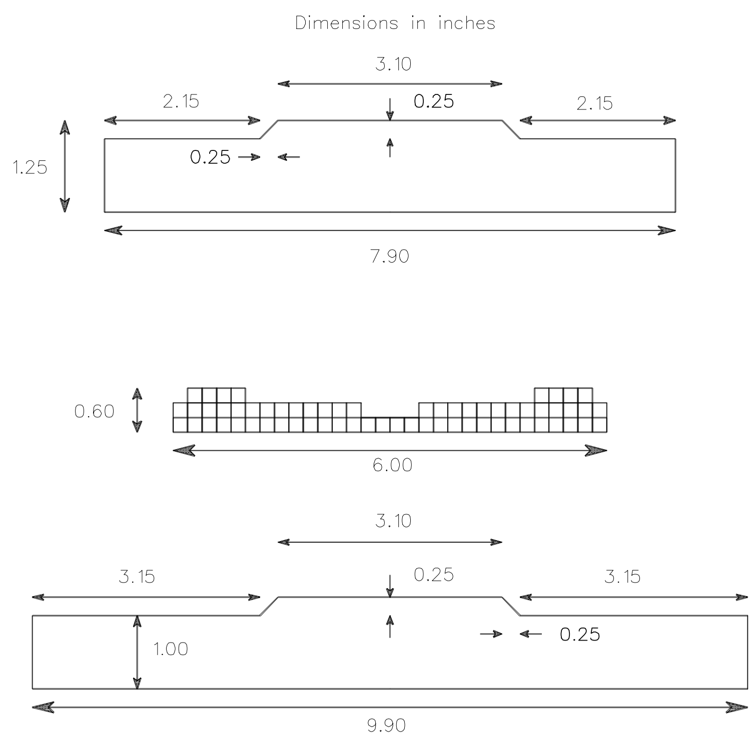

Fig. 1-b. Dimensions of the proposed steering magnet components.

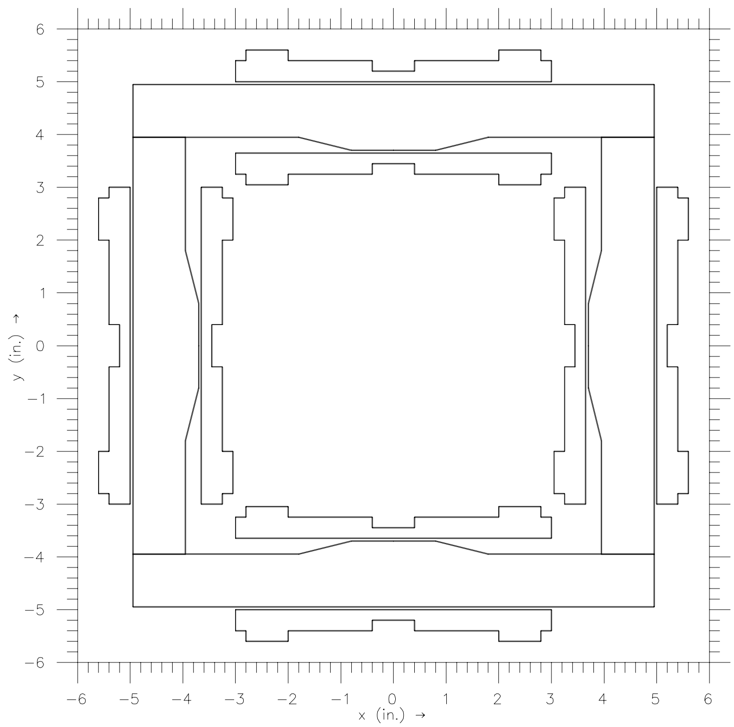

Fig. 2-a. Cross-section of the proposed steering magnet of ref[1]).

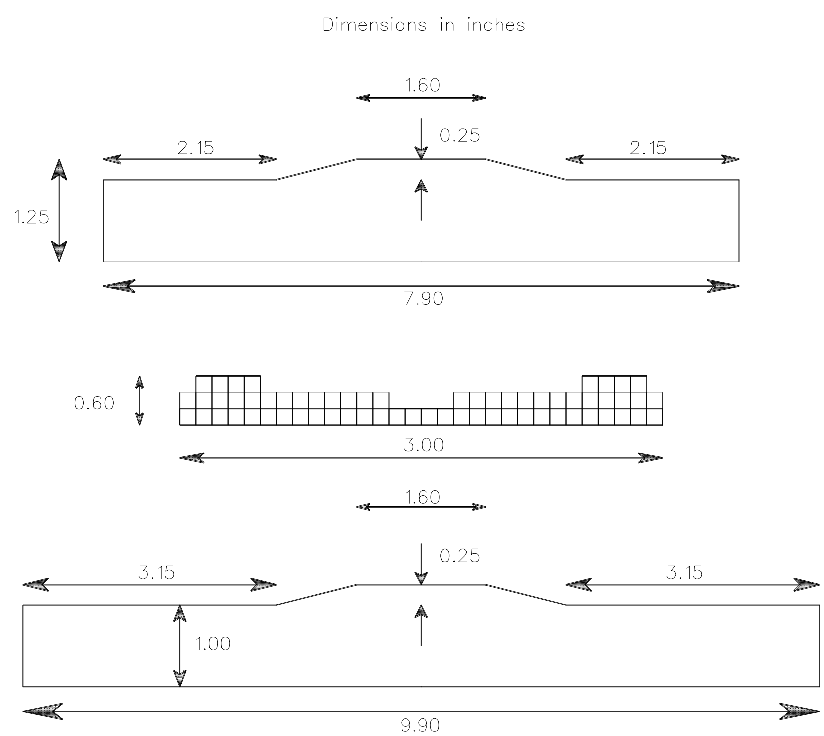

Fig. 2-b. Dimensions of the proposed steering magnet components of ref[1]).

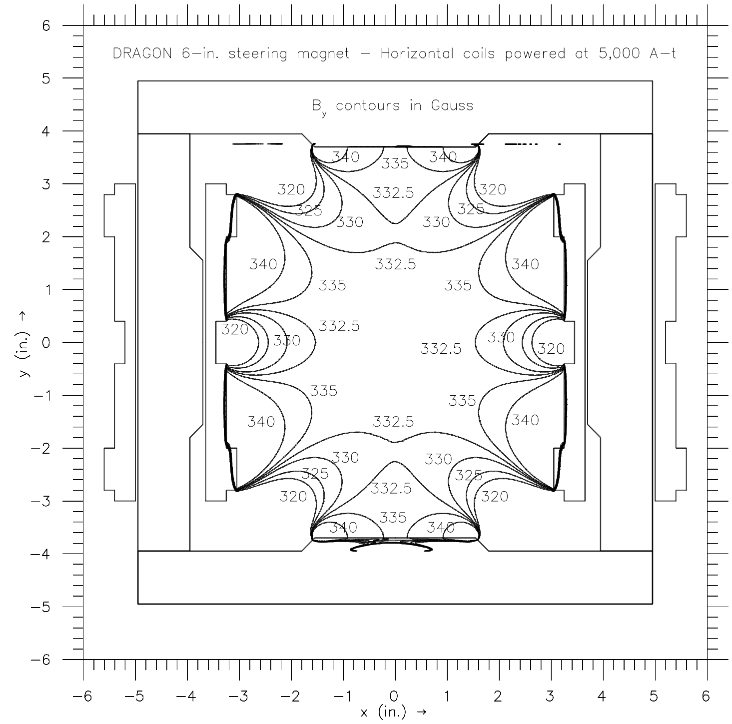

Fig. 3-a. Predicted distribution of B_y with only the horizontal coils powered.

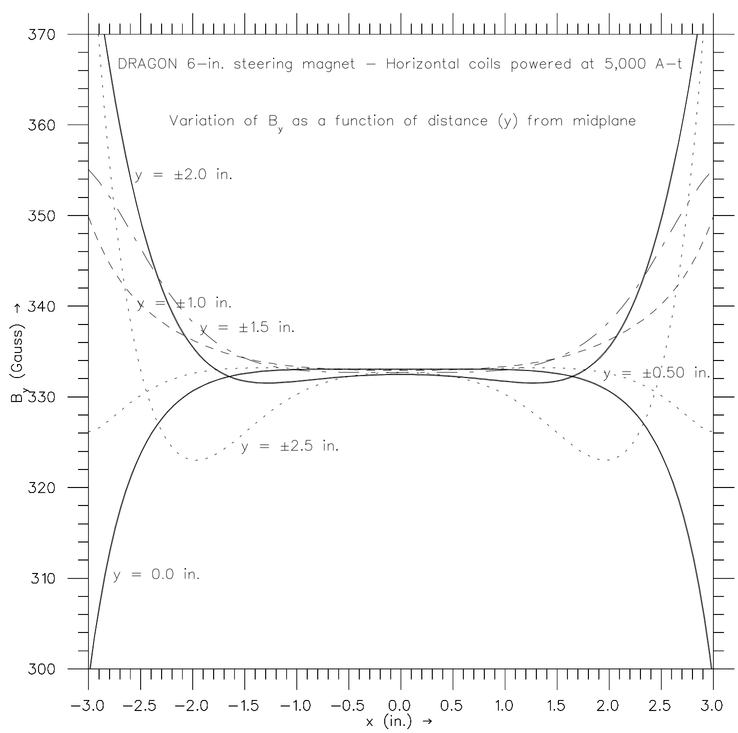

Fig. 3-b. Predicted variation of B_y with distance from the mid-plane with only horizontal coils powered.

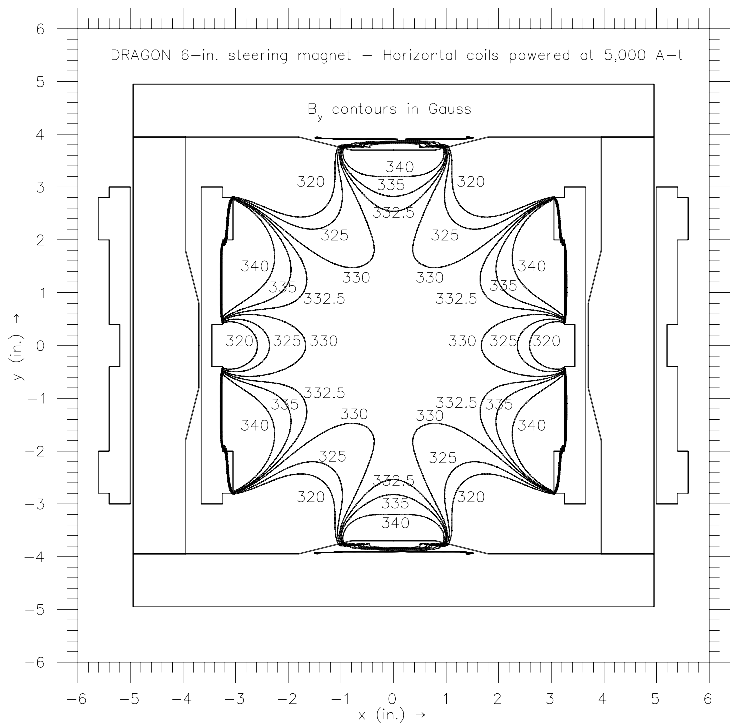

Fig. 4-a. Predicted distribution of ref[1] of B_y with only the horizontal coils powered.

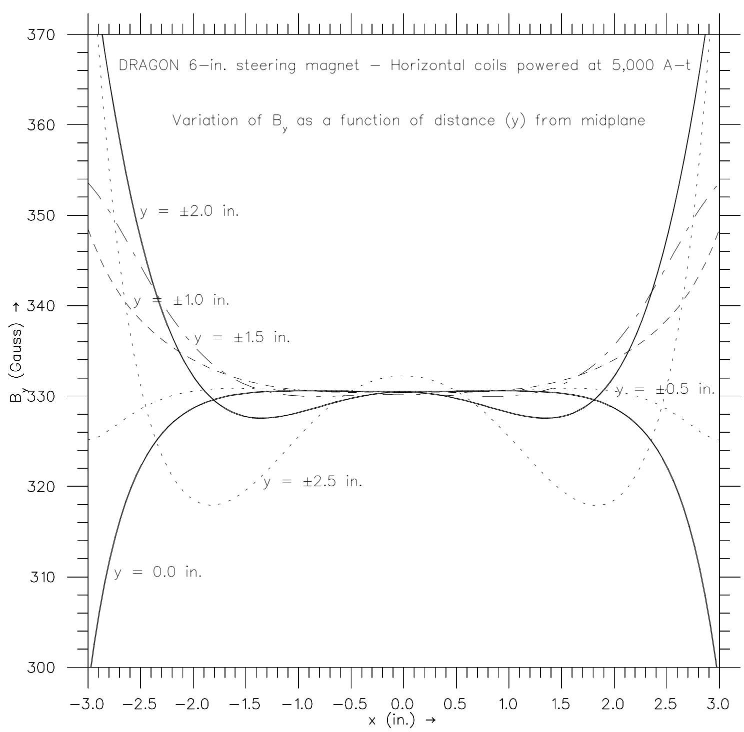

Fig. 4-b. Predicted variation of ref1 of B_y off the midplane with only horizontal coils powered.

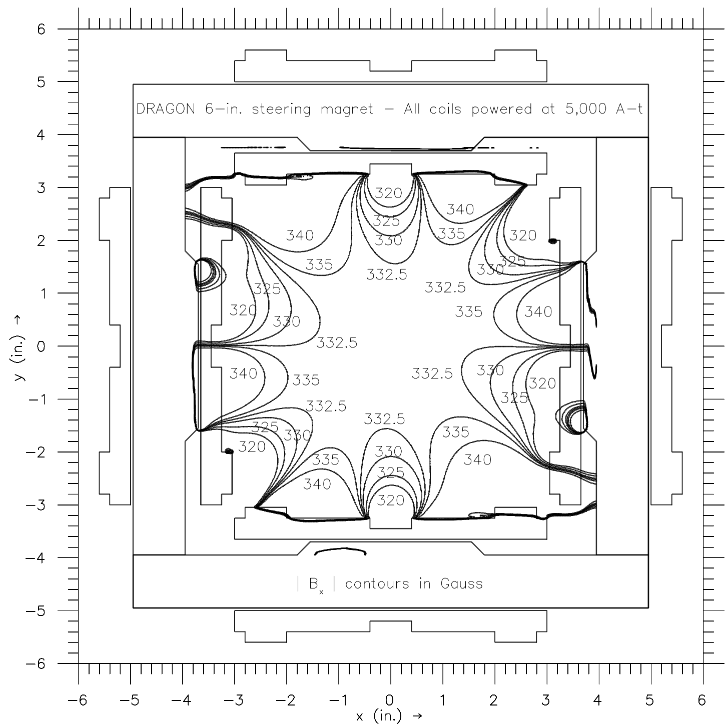

Fig. 5-a. Predicted distribution of $|B_x|$ with all coils powered.

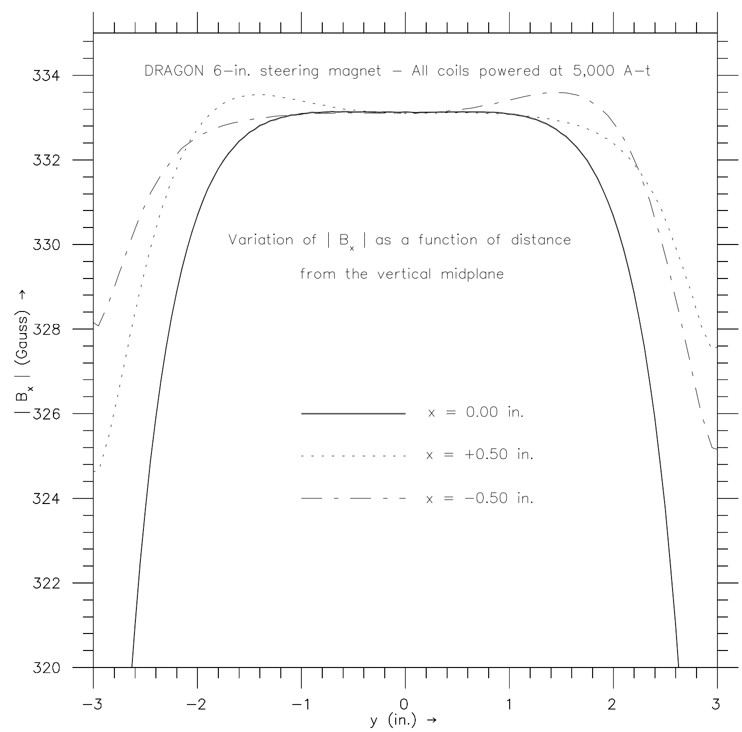

Fig. 5-b. Predicted variation of $|B_x|$ with distance from the mid-plane with all coils powered.

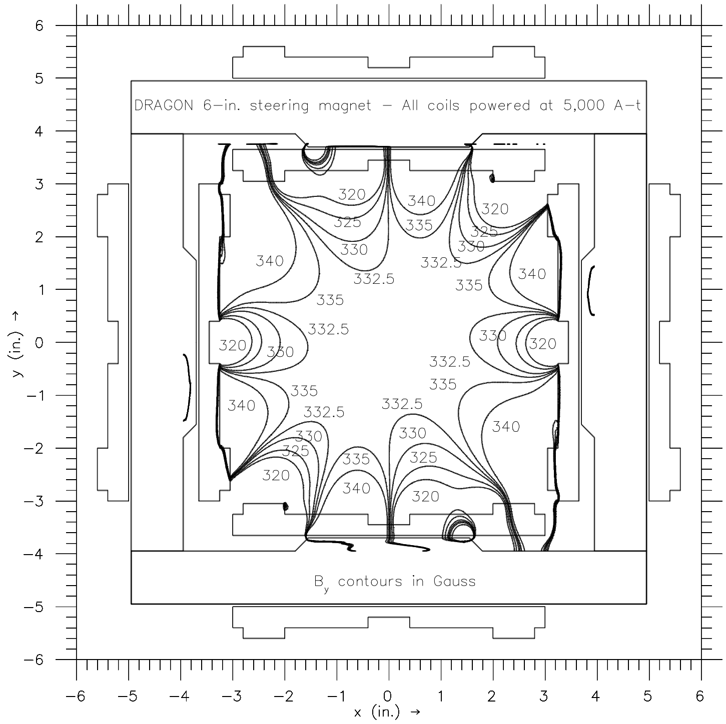

Fig. 6-a. Predicted distribution of B_y with all coils powered.

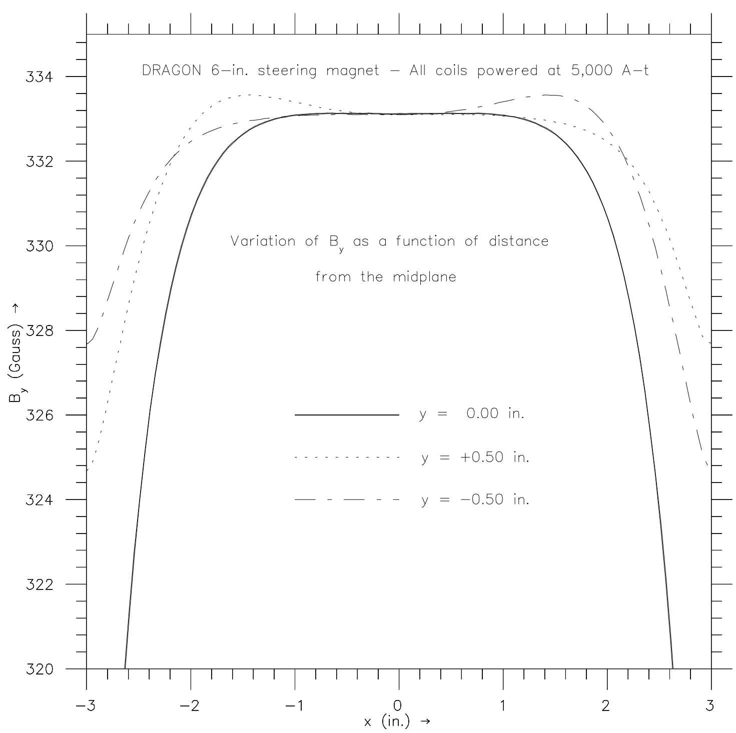

Fig. 6-b. Predicted variation of B_y with distance from the mid-plane with all coils powered.

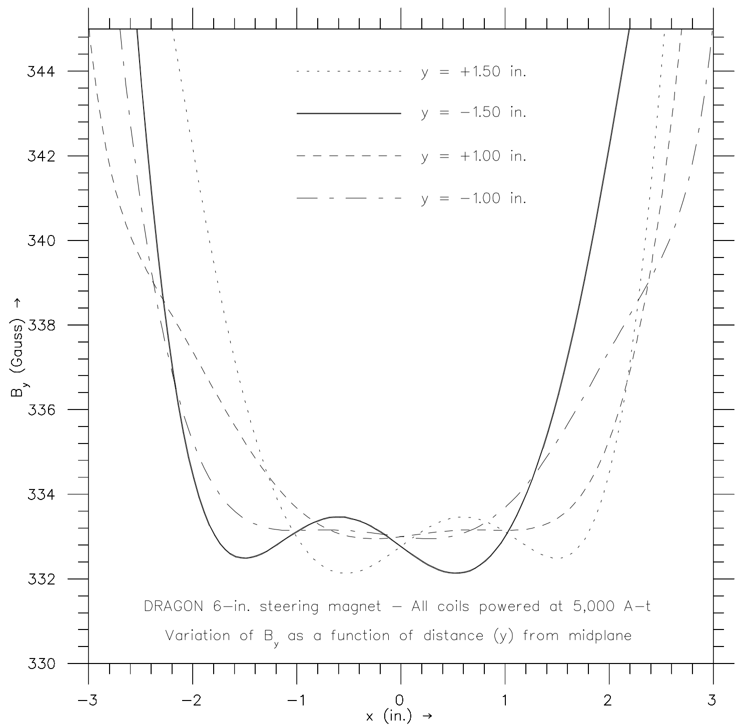

Fig. 7-a. Predicted variation of B_y with distance from the mid-plane with all coils powered.

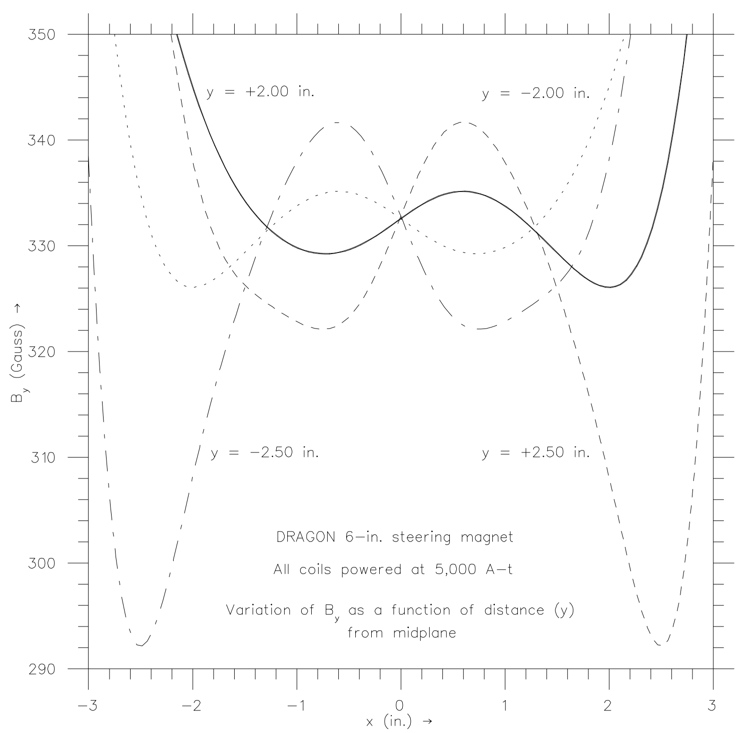

Fig. 7-b. Predicted variation of B_y with distance from the mid-plane with all coils powered.

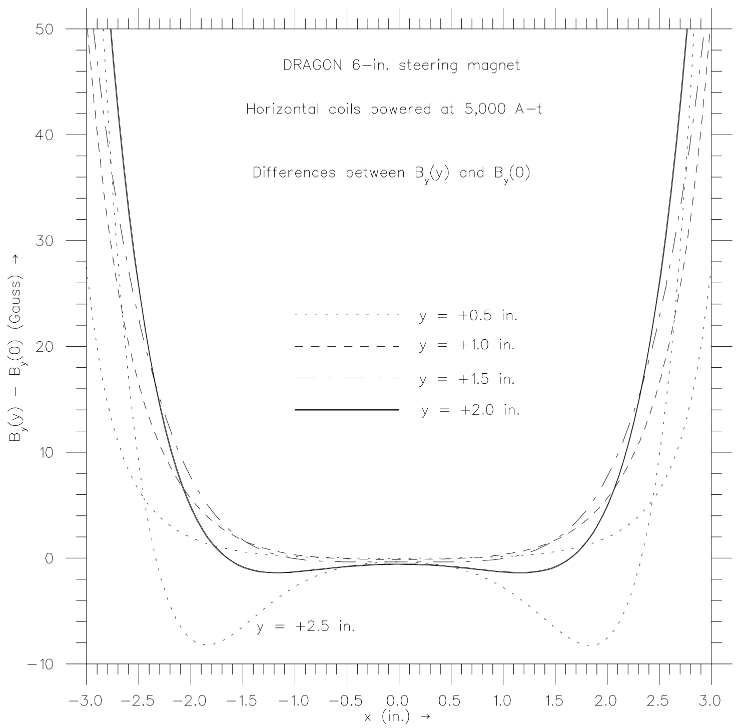

Fig. 8-a. Differences between off-midplane and midplane values of B_y with horizontal coils only powered.

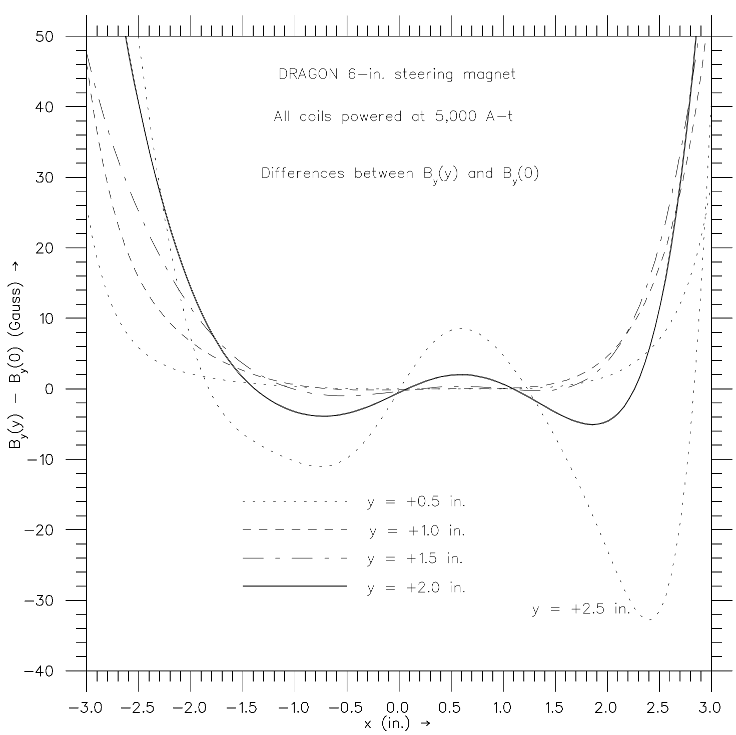

Fig. 8-b. Differences between off-midplane and midplane values of B_y with all coils powered.

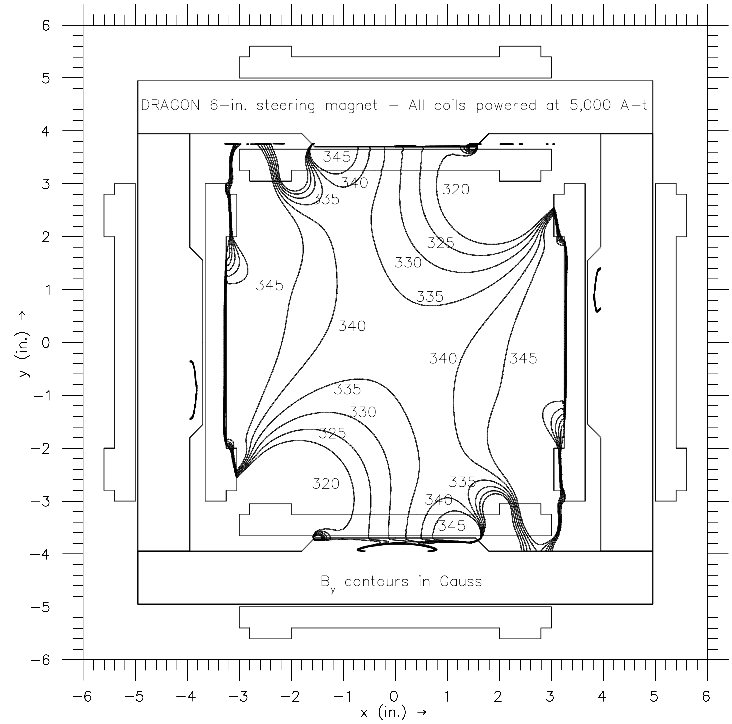

Fig. 9-a. Predicted distribution of B_y with the 'hole' removed from the coil and all coils powered.

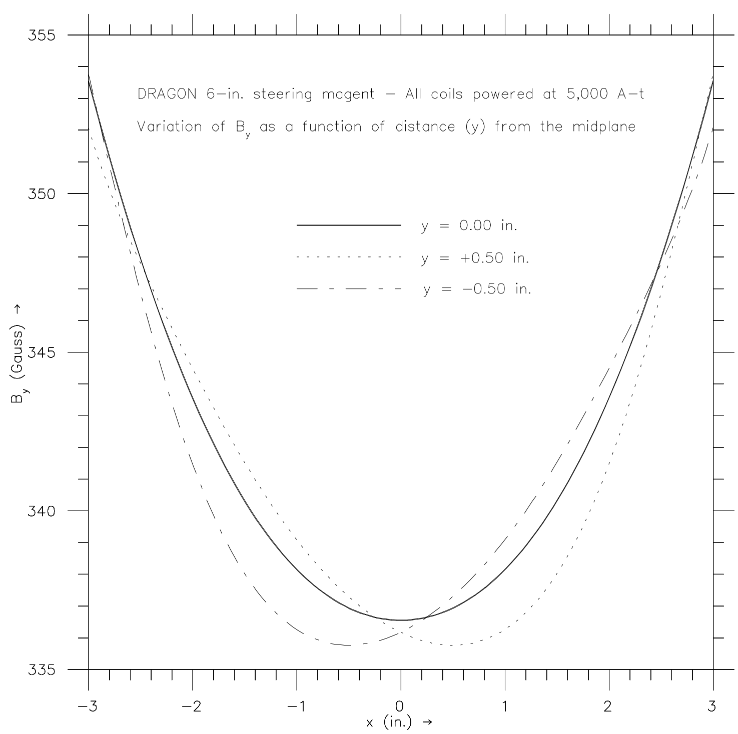

Fig. 9-b. Predicted variation of B_y off the midplane with the 'hole' removed from the coil and all coils powered.