MAGNET DIVISION NOTES

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Title: A High Field Combined Function Magnet Design for the Relativistic Heavy Ion Collider

Task Force: RHIC

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(This paper consists of 9 pages)

Introduction

The "Superferric" Magnet option using either the separated functions or the combined functions magnets has been proposed earlier[1,2] as a possible low cost design for the Relativistic Heavy Ion Collider (RHIC). In this Magnet Division note we report the combined function (CF) magnet designs for high fields. Most of the existing CF magnets for accelerators works with a maximum field of about 1.2T. Here, in particular, we discuss what has been done to raise that maximum limit to about 2T, making this magnet as one of the contenders for the RHIC magnets.

The required parameters for this magnet is given in Table 1 for the lattice proposed by J. Claus[3].

In section 2 a magnet design is given which is similar to the one described in Tech. Note 147[2]. It is a warm iron magnet. A hyperbolic profile has been used for the pole face and the positions of the conductors have been adjusted to obtain a constant B' over the required range, at least at the low fields. In Section 3 a magnet design is presented which allows the higher magnetic fields. It is a cold iron magnet. Our conclusions are given in Section 4.

The Magnet Design Program (MDP)[4] has been used for carrying out the following computations and analysis.

Warm Iron Magnet Design

The design is shown in fig. 1. The minimum gap between the poles is 5.84 cm and the maximum 15.04 cm. The pole face width is 24 cm and

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1. A Heavy Ion Collider Design Using "Superferric" magnets, E. B. Forsyth, K. F. Minati, T.R. Muller, R. A. Thomas, ATA Division Tech. Note No. 143, 16 Feb. 1984.

2. A "Superferric" combined function magnet design for a Heavy Ion Collider, E. B. Forsyth, T. R. Muller and R. A. Thomas, ATA Division Tech. Note No. 147, 26 March 1984.

3. RHIC Lattice, J. Claus, RHIC pg. 33, 22 Feb. 1984

4. MDP, Magnet Design Program, User's Manual, Collin D. Stewart, BNL 27417 (Informal Report).

the overall dimensions are 60 cm x 54 cm. The conductors are placed at the horizontal positions of x = ±12 cm. There is a 3 cm separation between the center of conductors and the iron on either side allowing sufficient space for the cable of Ref. 2. The vertical positions of the center of the RHS conductors have been adjusted to y = ± 4.2 cm to obtain a proper field profile (constant B' across the X axis). The vertical positons of the center of LHS conductors are ± 9 cm. When the RHS conductors are at the same vertical positions (± 9 cm), the B' falls from 303 G/cm to 319 G/cm in going from x = 9 cm to x = 4 cm on the X - axis. The forces on the conductors at I = 60 KA and at 1.5T central field are: On LHS conductors 1980 lb_f/ft and on RHS conductors 1470 lb_f/ft. It is presumed here that these forces and the heat leak due to them are acceptable in a warm iron magnet design. The performance of this model is summarized in Table 2 in terms of field harmonics. The harmonics have been computed* for a radius of 2.5 cm. The variation of B' across the X - axis is shown in fig. 2 for different central fields. It may be noticed that beyond 1.1 T, the harmonic components start growing fast and the constancy of B' is lost, making the above model unsuitable for the required central field.

Cold Iron Magnet

The design is shown in fig. 3. The major difference between this and the design described in the last section is in the structure near the conductors on the left hand side. The conductor themselves have been brought down to the X axis and the pole face has been modified there (Ref. fig. 1 and fig. 3) to encourage the flux lines to go more from this side. Also, along the same lines, the iron yoke has been made assymetric across the central line (parallel to Y axis) with more iron on the left hand side. The arguments behind making this type of model are the following:

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* A word of caution at this point. One may quesiton relying on the accuracy of MDP especially for the mesh size used to describe the hyperbolic pole profile, etc. Therefore, probably constancy of B' would be a better criterion for judging the performance of a magnet model in this kind of problem.

The last design (fig. 1) did not behave well at high fields because the iron at, and around the pole tip of the high field side (left hand side) got saturated more than on the other side. This causes flux to shift towards the low field side as the value of the central field rises which, as a result, modifies the variation of B' value across the X axis as compared to a constant value at low fields. By using additional iron on the left hand side (compare fig. 1 and fig. 3) and by bringing the LHS conductor close to the X axis we conteract for the above effect and force the flux lines to go more from the high field side (left hand side).

The results are described in Table 3 and in fig. 4. In Table 3 we summarize the field harmonics and in fig. 4 we plot the value of B' across the X axis at different field levels. It may be noticed that there is a marked improvement in the field quality at the higher fields; B' is now much more flat across the X-axis as compared to that in fig. 2. The desired value of B'/B (.0368) occurs at X = 0.52 cm.

However, the major problem associated with this design is the increase in the forces on the conductors. At 1.56T central field (60KA current in the coils) the force on the LHS conductors now become 6075 lb_f /ft, over three times higher than in the design described in the last section. The heat leak due to the structure needed for these high forces may not be acceptable in a warm iron model, therefore a cold iron model has been naively considered for this case. However, on the other hand there is a saving in the amount of iron required in this model, mainly due to a decreased height of the magnet. The overall dimensions in this design are 48 cm x 24 cm.

Conclusions

The cold iron design, described in this Magnet Division Note, demonstrates that it is possible to go to a significantly higher value of magnetic field in a combined function accelerator magnet than the one obtained presently. The B' profile across the X - axis is very flat as compared to the one in the conventional magnets (Ref. fig. 2 and fig. 4).

Moreover, it should be pointed out that this report describes the work done in the period of 2-3 months and therefore by no means claims the design to be the best possible one. Instead, it shows the direction to proceed to make a possible good design of a high field combined function magnet.

However, still in the present form of the design one can reach quite high fields, the value depends on the strength of the correction coils. We mention a safe value of the maximum central field to be 1.93T where the b'_4 and b'_5 terms are below 1 without using any correction coil. This magnetic field corresponds to the RHIC energy of 83.5 GeV/AMU. It may well be possible that with strong correction coils and with further improvements in the design one can go to as high field as 2.3T corresponding to the RHIC energy of 100 GeV/AMU.

Acknowledgements

Discussion and suggestions from Dr. J. Claus have been very useful during this work. Mr. R. Thomas provided initial help in working with MDP program. The encouragement from Dr. E. B. Forsyth for pursuing this topic is gratefully acknowledged.

Table I

Required Parameters for the Combine Function Magnet

Maximum Central Dipole Field (T)	1.7*
B'/B (cm^{-1})	.0368
Bending Radius ρ (m)	360.7
Magnet Length (m)	15.74
Max RHIC Energy (GeV/AMU)	73.5*
Horizontal Aperture (cm)	± 6.3
Vertical Aperture (cm), Iron to Iron	± 4.2

* The cold iron magnet design proposed in this note allows 1.93T magnetic field corresponding to the RHIC energy 83.5 GeV/AMU.

Table II

Field Harmonics in the Warm Iron Magnet Model at (0,0) for a 2.5 cm Radius

I (kA)	B (kG)	B/I (G/A)	B' (G/cm)	B'/B (cm^{-1})	b'_2	b'_3	b'_4	b'_5
20	5.567	2783	202.5	.0363	2.63	.85	.18	2.02
30	8.348	.2783	303.3	.0363	3.04	.92	.19	2.04
40	11.093	.2773	396.6	.0357	9.37	2.26	.22	2.04
50	13.615	.2723	452.6	.0332	30.28	5.59	.24	1.53
60	15.654	.2354	456.6	.0292	62.8	11.69	.49	1.37

Table III

Field Harmonics* at (.52,0) cm in the Cold Iron Magnet Model

I	B	B/I	B'	B'/B	b'_2	b'_3	b'_4	b'_5
(kA)	(kG)	(G/A)	(G/cm)	(cm^{-1})				
20	5.52	.276	203.5	.0369	2.02	2.69	.9	.72
30	8.26	.275	303.9	.0368	.89	3.05	.79	.86
40	10.86	.272	398.9	.0367	1.06	3.85	.61	1.06
50	13.3	.267	488.1	.0367	.8	4.27	.55	.97
60	15.27	.254	559.7	.0367	.83	4.86	.43	.76
70	16.76	.239	611.6	.0365	2.55	5.89	.6	.69
80	18.05	.226	652.7	.0362	3.84	6.69	.95	.56
90	19.24	.214	686.6	.0357	5.07	7.93	.98	.47
100	20.37	.204	709.2	.0348	7.76	8.49	1.31	.29

* Computed for a 2.5 cm radius

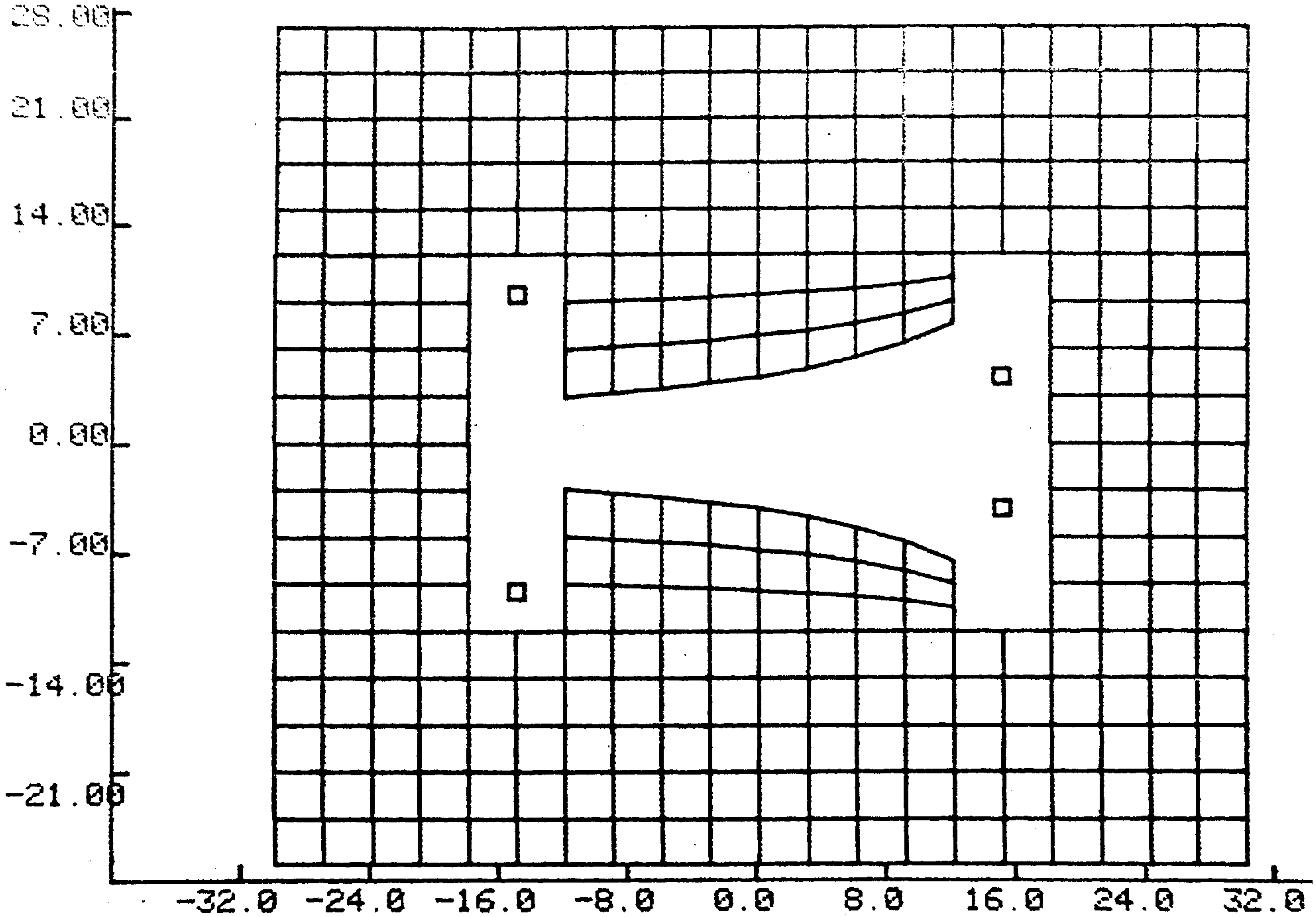

FIG. 1. WARM IRON MAGNET MODEL.

Variation of B' across the x-axis at various values of Central field

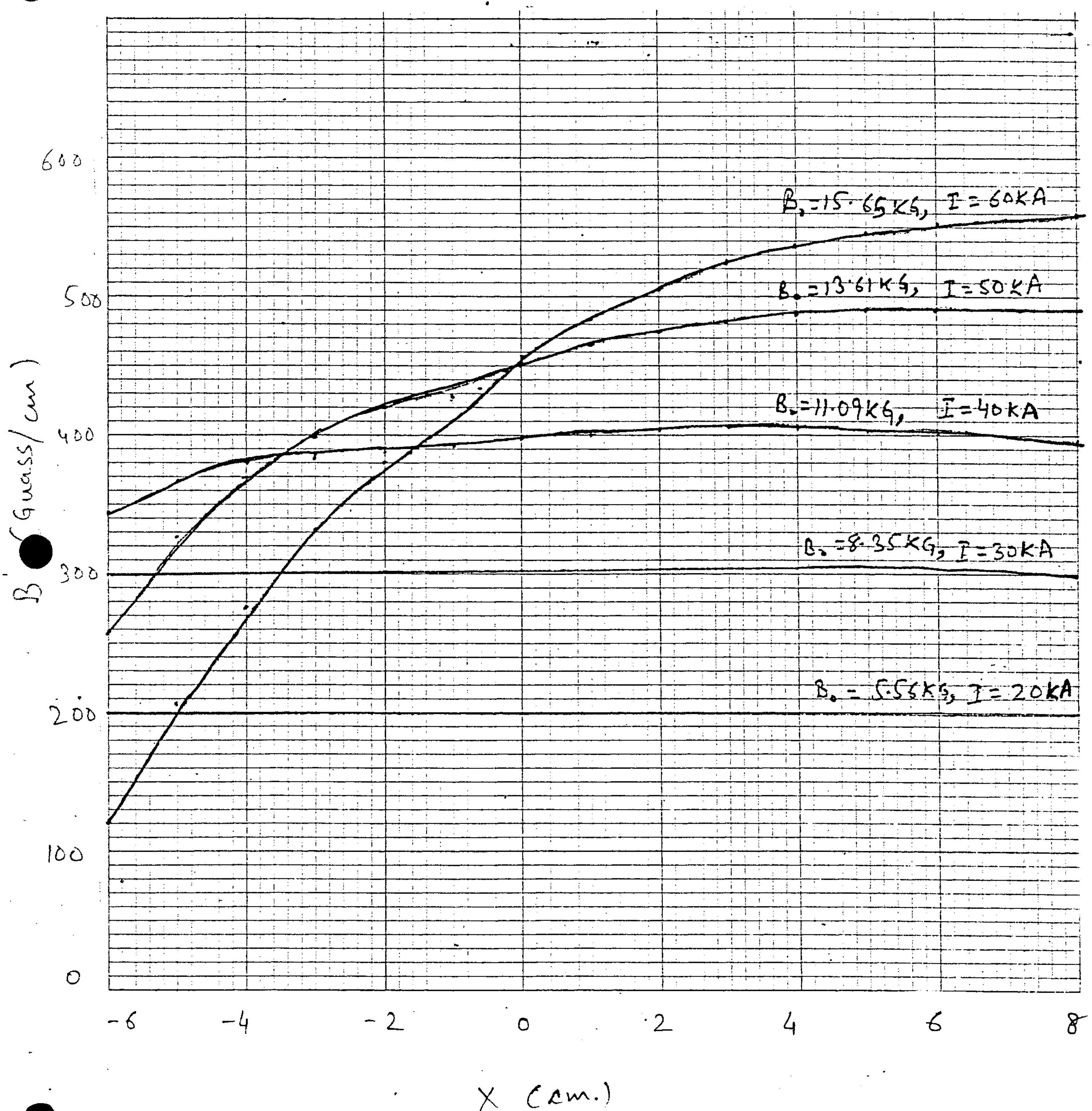

Fig. 2. Warm Iron magnet model.

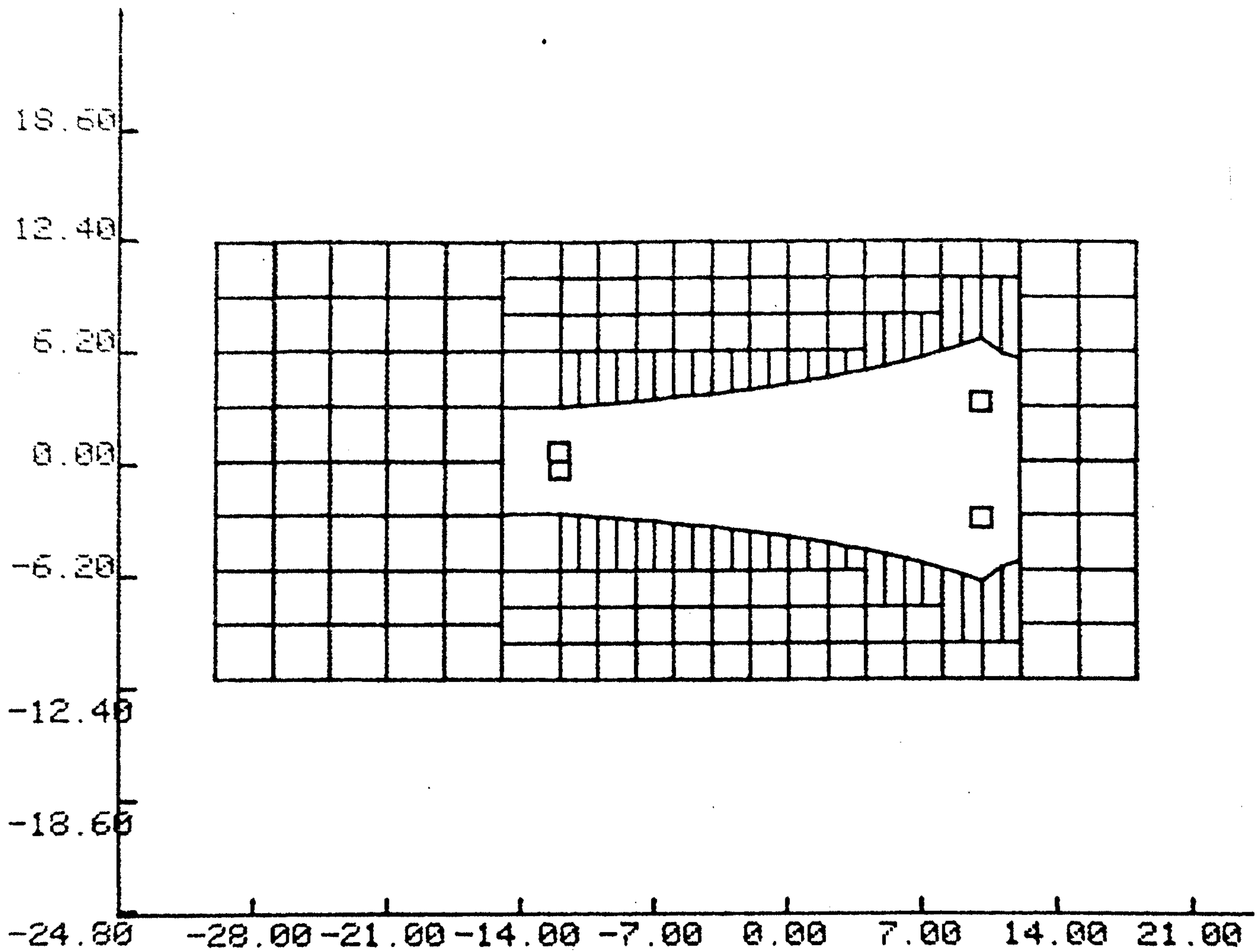

FIG. 3. COLD IRON MAGNET MODEL.

Variation of B' across the x-axis at various values of the central field (field at (.52, 0))

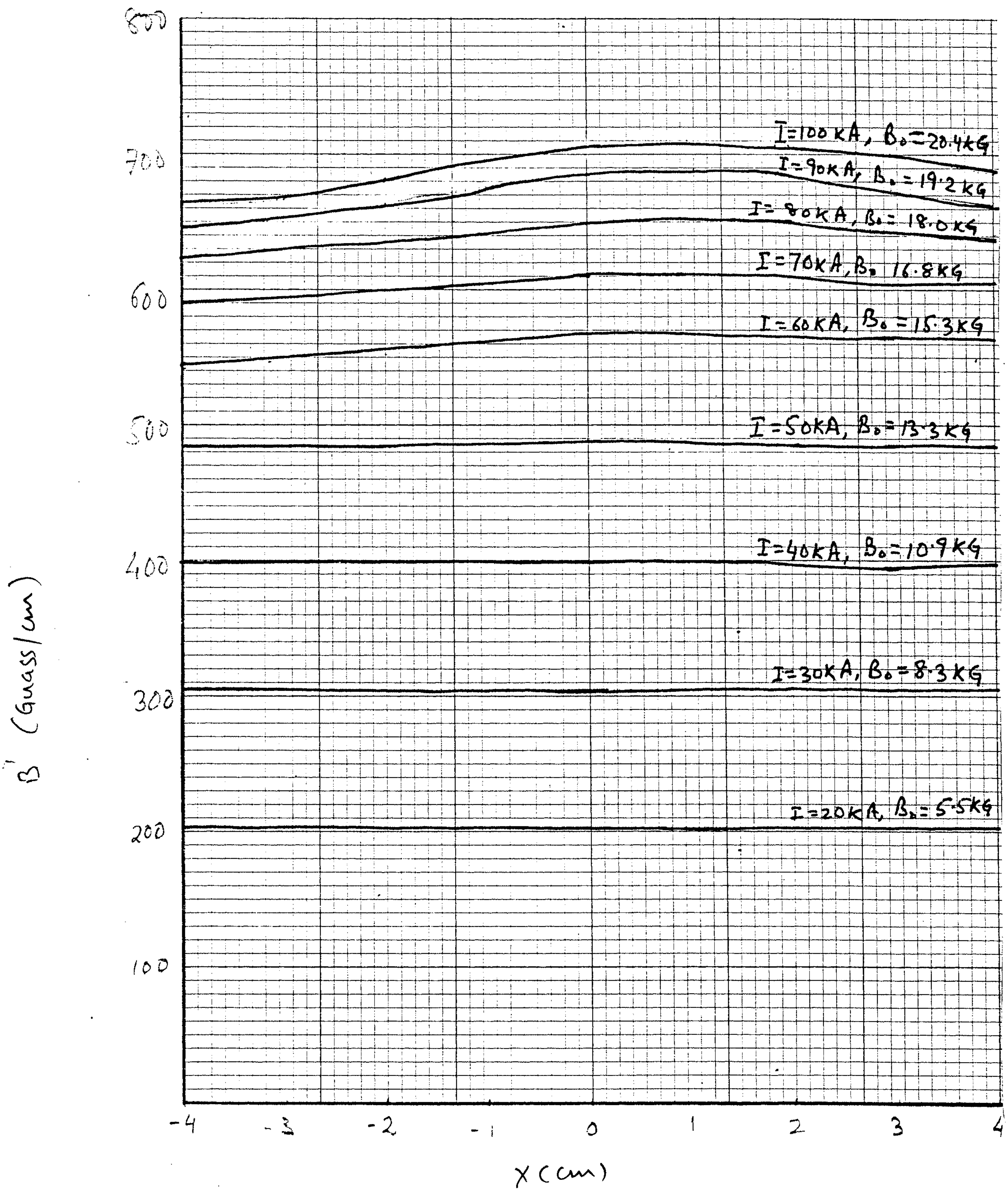

Fig 4 Cold Iron magnet model.