IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

A DESIGN FOR A HIGH FIELD COMBINED FUNCTION SUPERFERRIC MAGNET

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Summary

A combined function superferric magnet option has been investigated for the Relativistic Heavy Ion Collider (RHIC). The option requires the maximum value of the field in the magnet to be much higher than that achieved in any existing combined function accelerator magnet. A model is presented here in which a good field quality can be maintained up to 2T. It is done by carefully designing the yoke structure and positioning the coils in such a way that the iron poles tend to saturate evenly across the gap. A cold iron model might be necessary for this magnet.

Introduction

It has been proposed to use combined function (CF) superferric (field shape determined by the iron shape, but with superconducting coils) magnets to make possible a low cost design of the Relativistic Heavy Ion Collider (RHIC) to go in the existing CBA tunnel.[1] Most of the present CF magnets for accelerators work with a maximum magnetic field of about 1.2T. This corresponds to 50 x 50 GeV/amu RHIC energy as against the users request of 100 x 100 GeV/amu. A model is developed here with which it may be possible to reach 2T, corresponding to 85 x 85 GeV/amu RHIC energy. In particular we will discuss what approach has been used in designing this model. The parameters for the model have been taken from the lattice of J. Claus,[2] with the specified field gradient value $B'/B = .0368/\mathrm{CM}$.

Let us first examine the additional problems present (in trying for high fields) in a CF magnet which are not present in a separated function (SF) magnet. In an SF magnet the field is symmetric about the vertical (y) axis. Saturation occurs simultaneously on the two sides of the y-axis and the field lines do not move from one side to another as the iron saturates (this is strictly true only if the iron yoke is also symmetric). It is, however, not true in a CF magnet, since by definition there is a higher field on one side than on the other. The pole tip on that side saturates earlier and the field lines move from the high field side to the low field side. This changes the field gradient across the X-axis and creates various harmonics, especially the odd harmonics. It should be pointed out that one sees the effects of the onset of saturation at a lower central field in a CF magnet compared to an SF magnet.

The Model

A typical model of an H-shape combined function magnet is shown in Fig. 1. We present our model in Fig. 2. It has 8.4 cm vertical aperture (iron to iron) and 23 cm horizontal aperture (coil to coil). The cross section of the coils is $1 \mathrm{x} 1\ \mathrm{cm}^2$. Both models have a hyperbolic pole profile as required for a CF magnet. They differ in the positions of the coils and in the structure of the yoke. In reaching to the model shown in Fig. 2 we investigated different positions of the coils for the following purpose:

1. To obtain correct harmonics at low fields where iron does not saturate.
2. To control the saturation of the iron in the vicinity of the coils. This, in turn, affects the harmonics at the field levels where the saturation is important.

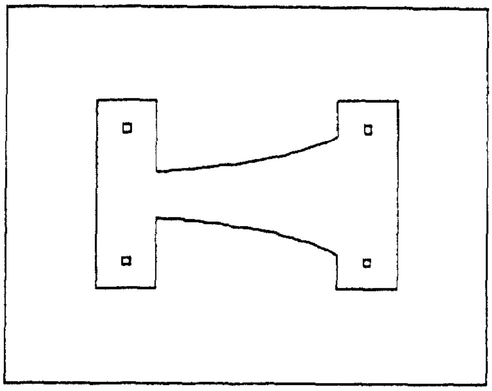

Figure 1. A conventional CF magnet.

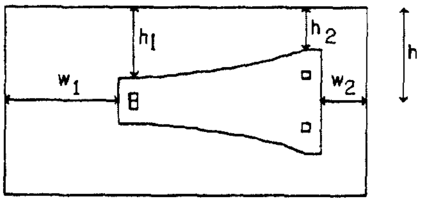

Figure 2. Our proposed CF magnet.

However, the main optimization in reaching to this model has been in the yoke structure. Referring to Fig. 2, widths w1 and w2 and heights h, h1 and h2 are the parameters which can be optimized. We did the optimization in two steps. In the first step we varied the height h, h1 and h2 and kept w1 = h1 and w2 = h2. With this we tried to minimize the variation in the permeability of the iron across the pole face. We find that to make such a procedure work effectively, the height h should be considerably less than in usual models as in Fig. 1. This lower height brings the pole face into saturation at somewhat lower field. However, then the remaining parameters more effectively control the saturation across the pole face. We investigated it using the computer code *GFUN*[3] by looking at the variation of the permeability in different regions of the iron at the pole face. Once this variation in permeability is minimized, particularly at the fields where the iron is highly saturated, the first step is completed.

The model can be further improved in the second step by making finer variations in various heights and widths. The shape of iron near the coils may also be made different. With each such variation, we made several runs of the computer program to scan the magnetic field from minimum to maximum. We looked for the model which produced a minimum variation in various harmonics during such scan, although one may not be able to generate a model which will have minimum variations in all the harmonics simultaneously. We looked for a model which, during such scan, has harmonics of order higher than b_4 (defined in Table 1) below an acceptable limit and others either remain

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*Work performed under the auspices of the U.S. Department of Energy.

0018-9499/85/1000-3687$01.00© 1985 IEEE

in the acceptable limit or are correctable with the help of additional correction coils having practical strength; or, if the correction is done outside the magnet, the demand for space for the correction magnets required do not become too excessive. The variation of the harmonics as a function of coil current is given Table 1. The harmonics higher than b_4' are sufficiently low at all currents. The magnet should be acceptable for an accelerator up to 1.3T field without any need of correction coils. The quadrupole and the octupole harmonics require modest correction from 1.3T to 1.7T; at higher fields the correction required grows steadily. The final calculations have been done with the computer code POISSON.[4]

Table 1

Field Harmonics for 2.5 cm Normalization Radius

I	B	B/I	B'/B	b_2'	b_3'	b_4'	b_5'
KA	T	T/KA	CM^{-1}	10^{-4}	10^{-4}	10^{-4}	10^{-4}
10	0.30	0.03	.0368	0.1	-0.7	0.0	-0.2
20	0.60	0.03	.0368	0.1	-0.7	0.0	-0.2
30	0.86	0.03	.0368	0.1	-0.7	0.0	-0.2
40	1.16	0.029	.0368	0.3	-0.3	0.0	-0.1
50	1.39	0.028	.0367	0.6	-0.2	0.0	0.0
60	1.54	0.026	.0365	0.7	0.5	0.2	0.0
70	1.66	0.024	.0363	0.4	0.8	0.5	0.0
80	1.77	0.022	.0359	0.2	1.2	0.5	0.0
90	1.87	0.021	.0355	-1.5	2.2	0.5	0.1
100	1.97	0.02	.0346	-7.2	4.4	0.8	-0.2
103	2.00	0.019	.0344	-9.7	4.6	1.2	-0.3
110	2.07	0.019	.0334	-14.8	3.8	2.4	-0.4
120	2.15	0.018	.0318	-16.8	0.8	3.0	-0.1

where the harmonics $b_n'(n = 1,2,3...)$ are defined as

$$\Delta B/B_o = \sum_{n=1}^{\infty} b_n'(r/r_o)^n ,$$

with r being the radius on the midplane and r_o the normalization radius.

The force at 2T central field on the conductor on the low field side is about 60 MN/m at -4.4 degree and on the conductor on the high field side is about 130 MN/m at -124 degree. 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 may be required for this magnet.

Conclusion

The model developed here demonstrates that it may be possible to maintain an acceptable field quality up to 2T in a combined function magnet. The requirement for the corrections start from 1.3T but remain very low up to 1.7T. The correction required grows somewhat rapidly after 1.7T but seems to remain quite practical up to 2T.

The superferric CF magnet option, however, is not being considered for RHIC, mainly because it does not provide the required 100 x 100 GeV/amu collision energy. The model was developed as a part of the feasibility study and no detailed analysis has been done on various aspects of it, such as the magnetization of the coils, and the placement of the correction coils. The model, however, should be useful in future proposals where a combined function magnet option would otherwise have to be ignored on the ground that one cannot attain such high fields in them. In these magnets, where the field shape is determined by the pole shape, the random error in field harmonics is much lower than in those (e.g. in cosine theta magnets) where the field shape is determined by the coil shape.

Acknowledgements

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

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