DESIGN CONSIDERATIONS ON THE SSC COLLIDER QUADRUPOLE MAGNETS

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ABSTRACT

On the basis of the existing experience from the HERA project and the development work at LBL on the Collider Quadrupole Magnets (CQM) a final design of the collared coil is under development at Siemens. Short model magnets are built early in the program to support the analytical design work. Coil cross sections alternatively to the LBL baseline concept are considered.

1 INTRODUCTION

The Babcock & Wilcox/Siemens team in 1991 had been awarded the contract for development magnets (CQM) up to the low rate initial production. The prototype, preseries and LRIP phases will lead to the final design and manufacturing concepts ready for full rate production. Technically the work is based on extensive and successful development efforts including manufacture of several full length quadrupoles at LBL. [1] In addition experience is available from the successful manufacturing of HERA quadrupoles, which used some different approaches.

Starting from the LBL approach for the design of the quadrupole coil cross section a final design of the collared coil is being developed covering magnetostatics and structural analysis using finite element methods. In parallel manufacturing design for short model magnets is performed for building first 1-meter long magnets in order to have a feed back from manufacturing early in the program.

2 BASELINE DESIGN OF COLLARED COILS

Table 1 lists the dominant features of the two approaches to develop and build collider type of quadrupoles within an industrial environment. Main parameters of the magnets are also presented for comparison.

Table 1: Design comparison LBL versus HERA

	LBL-CQM	HERA-CQM
Cable		
Dimensions	9.73x1.166	9.50x1.50
Insulation	1x Kapton 100 µm	2x Kapton 50 µm
Coil		
Diameter, Inner	40 mm	75 mm
Length	~5 m	~2 m
Windings, Inner	8	11
Windings, Outer	13	16
Configuration		
Layer Crossover	splices	splice free
Collar Sheet	4 piece, Al	2 piece, SS
Insulation Scheme	Kapton, prepreg	Kapton, prepreg

Based on the design of the coil cross section from the development program at LBL, see Figure 1, a baseline concept for the collared coil is defined integrating special manufacturing features of the collared coils for the HERA quadrupoles. This includes first of all a splice free winding of the inner and the outer layer which already proved to be successful for the HERA quadrupoles.

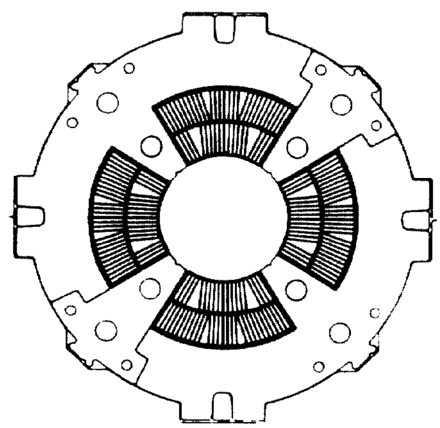

Figure 1: Collared coil cross section design by LBL

Table 2 shows the pro's and con's of splice free winding affecting magnet performance features and manufacturing features as well.

Table 2: Pro's and con's of splice free winding

Advantages	Affects
. Loss-free interconnect	. Cryogenics, Risk
. High form stability of joint two-layer coil	. Field, Structural
. Allows for full length collaring	. Manufacturing, Structural
. Facilitated current feedthrough	. Manufacturing
. Fewer parts	. Manufacturing
. Cost reduction	. Manufacturing
Disadvantage	
. Handling operation of inner layer	. Manufacturing
Neutral	
. Double curing of inner layer	

A second feature taken over for our baseline design from the HERA quadrupoles is the use of a fishbone type GFRP spacer between the layers. It provides a well defined winding surface for the second layer as well as some helium transparency of the coil layer stack being favourable for recovery after quench.

Of special importance to manufacturing is the fact that splice free winding opens the option for collaring with pole free but otherwise unchanged collars. As can be seen from Figure 2 an end configuration was developed which allows for complete assembly of the collared coil including intercoil splicing and also the option to apply axial prestress of the coil end region, if found necessary from structural analyses. Thus clear interfaces are provided to further manufacturing steps and ease of separate testing. No new type of pieces need to be handled and collaring can be done more or less as a continuous process in vertical position of the preassembled coils.

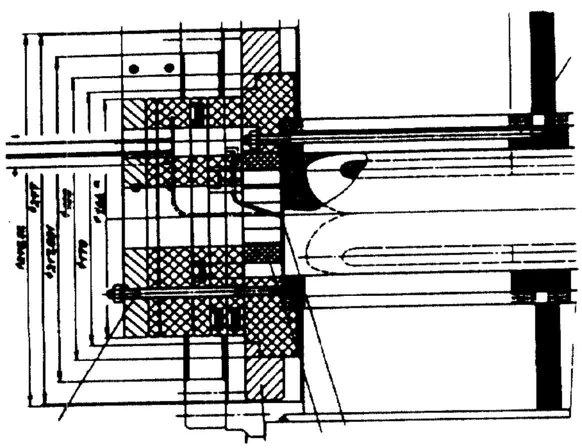

Figure 2: Collared coil end configuration

3 ANALYTICAL DESIGN

Magnetostatic calculations are performed applying the computer codes MAFINA [2] and MFB 3D [3]:

- MAFINA: Vector potential theory based on a finite element method (FEM) approach
- MFB 3D: Integral method based on Biot-Savart

Table 3 Multipole expansion for the baseline coil cross section, Reference radius = 0.010 m

	Conductor block Approximation (MAFINA) I = 6500 A	Conductor cable Approximation (MAFINA) I = 6500 A	Conductor cable Approximation (MFB3D) I = 6500 A	Specied Values
	without iron yoke [units]	without iron yoke [units]	without iron yoke [units]	[units]
b_5	0.498	0.174	0.175	< 1.399
b_9	0.161	0.093	0.086	< 0.612
b_{13}	0.064	0.066	0.057	
b_{17}	0.002	0.003	0.003	< 0.133
b_{21}	0.008	0.008	0.001	
B1[T/m]	200.065	201.502	201.433	-

In a first step the LBL coil cross section was modified with respect to the insulation system and boundary angles giving our baseline coils cross section. Calculations were made for a conductor block and for a conductor cable approximation. The cable has a keystone angle of 1.2°. This coil cross section was optimized using MFB 3D with respect to the multipole coefficients varying the positions of the cable.

A comparison of the results is shown for an air core coil system in Table 3.

Structural analysis is performed developing finite element models for the collared coil. After a first model according to the LBL design with a four-piece collar (see Figure 1) to reproduce LBL results we now have adapted the model for a two-piece collar. The finite element model is shown in Figure 3.

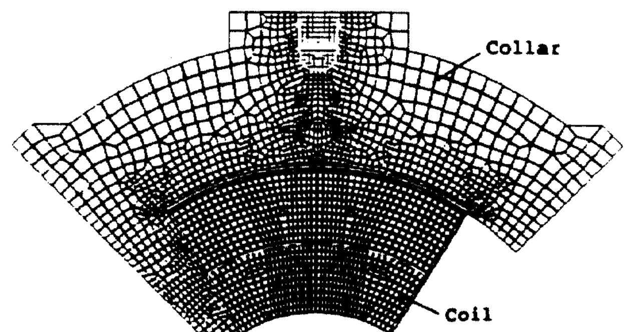

Figure 3: Finite Element Model for one-fourth of the collared coil cross section (two-piece collar)

The load cases which are considered are:

- prestress
- cool down
- Lorentz forces
- Superposition of these load cases.

The results obtained so far with this finite element model are preliminary and under evaluation.

A sensitivity study giving final results is planned and will include the variation of the following boundary conditions:

- prestress on the coil by the collar
- orthotropic material data
- geometry of the key-way region
- friction coefficient between coil and collar

The choice of the material data will be supported by data measured from the first manufactured short coil for the program see below.

4 ALTERNATE COIL CROSS SECTION

Beside the coil cross section of the baseline design we are investigating alternate cross sections for

- different keystone angles for the cable 1.64°, 1.90, 2.15°
- wedgeless outer coil layer
- stepped pole.

This investigation is performed using the code SSCMAG of SSCL which was implemented at Siemens recently. As an example a data sheet of one of the cases investigated so far is shown in Figure 4.

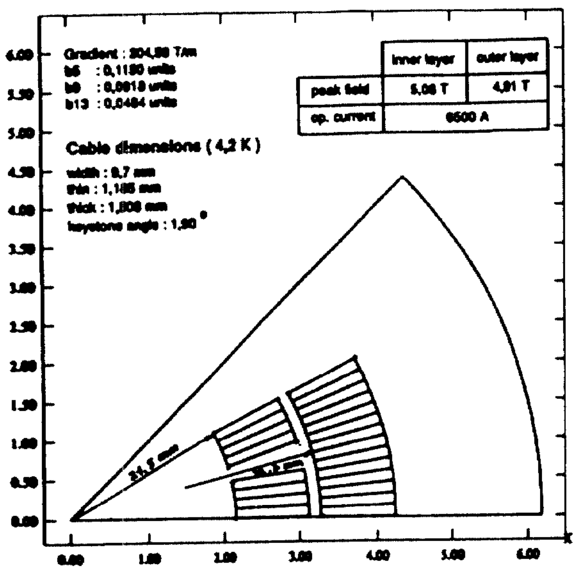

Figure 4: Example of a data sheet for magnetostatic analysis of a coil cross section alternatively to the baseline coil cross section (no proposal)

5 MODEL MAGNET PROGRAM

To gain manufacturing experience with coil winding and collaring, yoke assembly and skinning, and to perform cold tests a program is defined for manufacturing of seven 1-meter long model magnets beginning in March 1992 before starting with prototypes and preproduction magnets. It is a main goal to produce magnets with such a quench performance, that only a minimum number (preferable none) training steps are required to reach short sample critical current.

The second objective of this model magnet program is to support the final design of the quadrupole magnets. The main technical issues are:

- varifying of design characteristics as indicated in Table 1.
- optimization of the insulation system of the coil
- take use of material data from manufactured coils
- measurement of pressure at the coil/pole interface by strain gauge packs
- investigation of coil performance with and without axial prestress
- probe different collared coil/yoke interface designs: sliding concept versus line-to-line fit concept
- investigation of quench behaviour
- first cycle tests

Depending on the results from the performance of the first model magnets it will be decided whether a coil cross section different from that of the baseline design will be realized for two of the seven magnets.

6 CONCLUSION

The final design of the Collider Quadrupole Magnets is in good progress. Although based on the LBL design for the coil cross section certain characteristic differences are integrated forming our baseline design. The collared coil must still be optimized with respect to the structural aspects. An alternate coil cross section is under consideration. Essential support of the final design is expected from the manufacture of seven 1 m long model magnets.

REFERENCES

[1] C. Taylor et al., "Quadrupole Technology Briefing for the Superconducting Super Collider", LBL, Berkeley, 1990

[2] E.-D. Krause, M. Ritscher, R. Röckelein "Zweidimensionale Magnetfeldberechnung mit Finiten Elementen". Vortrag zum X. Internationalen FEM-Kongress Baden-Baden, 16./17.11.1981 Siemens AG, ZFEBT PE42

[3] P. Henninger MFB3D-Version 2.1 3D-Magnetfeldberechnung für Luftspulensysteme Benutzerhandbuch I, Juli 1989 Siemens AG, ZFEBT PE42