A Software Package Linking PE2D and ANSYS for SSC Magnet Design

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ABSTRACT

The design of the Cold Mass(CM) of superconducting magnets at the Magnet Systems Division(MSD) of the Superconducting Super Collider Laboratory(SSCL) involves among others the optimization of field quality and structural performance as related to the quench behavior of the magnets. It is desirable to be able to study the changes in field quality due to dimensional changes of the cold mass components under stress as the magnet is cooled and energized. This document describes a software package of functions which enable the computer aided study of this aspect of cold mass design.

INTRODUCTION

The main motivation to develop a computer based data processing loop for the design and analysis of the CM SSCL/MSD magnets has been the need to increase the productivity for this phase of the overall development effort.

In addition the automatic communication among the various CAE software modules involved ensures better reliability, repeatability, accuracy and controllability of the analysis procedures.

In a typical SSCL/MSD-CM design evaluation scenario - as shown in Figure 1. - initially the one or two layer dipole/quadrupole magnets with circular iron yokes are optimized so that the sum of squares of the difference between desired and actual harmonics is minimized. COP7 [1] an interactive specialized program for the optimization of CM cross sections is utilized.

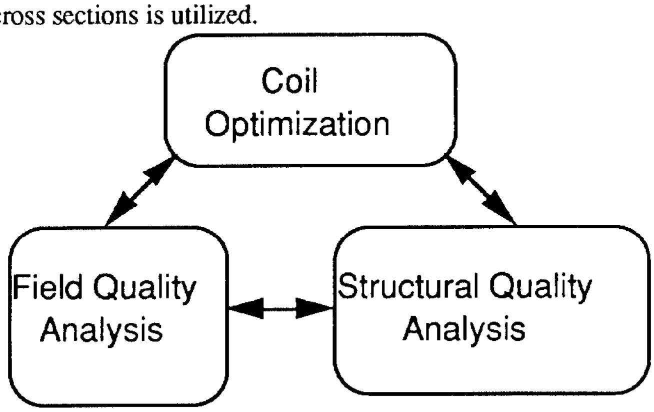

Figure 1. CAE Cold Mass Design Cycle

The resultant CM geometry is further analyzed for field quality using PE2D a 2-dimensional xy and axisymmetric static and dynamic electromagnetic analysis package [2-7]. Providing that initial field quality criteria have been met structural analysis is performed for the cross section employing ANSYS [8] the chosen general purpose finite element program. The ANSYS analysis demonstrates the deflection behavior of the CM as it is energized and cooled down.

It is therefore highly desirable to be able to communicate necessary information back and forth among these codes relatively quickly since a number of iteration loops may be required before an acceptable CM design is achieved.

COPAL

Manipulation and passing of data during the design cycle is accomplished by a set of codes referred to as Coil Optimization PE2D ANSYS Links(COPAL). A block diagram of COPAL is shown in Figure 2 and a more detailed account of these software modules is given below.

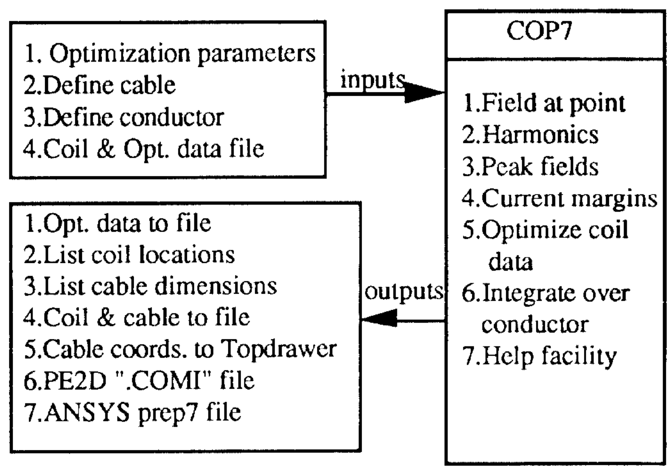

Figure 2. COPAL i/ps calculations and o/ps

COP7

COP7 is an optimization program used to generate coil configurations for a given set of required harmonics. The user enters the cable to be used, the collar width, the desired harmonics, and an initial configuration. Data to this code is input either interactively or by reading a data file from a previous run. The optimization routine then varies the turns in each coil, the size of the wedges, the inner radius and the current to produce the correct field. The number of turns is allowed to be non integer so that optimization occurs over a continuous range; the operator then adjusts the design for integral turns and reoptimizes. At any point the coil data can be listed, or the peak fields, margin, forces and harmonics calculated. Fields are calculated using complex integration over the cables. The cable in general has a keystone angle with the result that the current density varies across it. The distribution is modelled by two lines running from the thin to the thick edge of the cable, in the same way as rows of strands. The effect of the iron is modelled by assuming that the iron is circular and infinitely permeable. This is an approximation to the real situation, which is modelled more accurately by PE2D.

COP7 to PE2D

PE2D is a finite element program used for solving 2D electromagnetic problems with nonlinear iron. COP7 generates an input file for PE2D which includes the coil locations as shown in Figure. 3 for the PE2D model of the collider dipole. There is also an option to include a suite of standard yoke designs. Non standard yoke configurations can be added manually.

The presence of saturable iron, as well as a non circular iron boundary, mean that the harmonics will be slightly different from those calculated with COP7 and will also vary with current. For example, the dipole transfer function, which is defined as the ratio of dipole field to current, will decrease as the current increases and the iron saturates. This effect can be accurately modelled with PE2D. The program is also used to calculate a number of time-varying problems such as forces on a beam tube due to Eddy currents during quench.

Analysis of the results from PE2D may indicate that the design should be reoptimized with COP7 for a slightly different set of harmonics. The revised design can then be verified in PE2D once again. The interface between COP7 and PE2D greatly reduces the amount of time required to produce a PE2D model and therefore makes design iterations of this type possible.

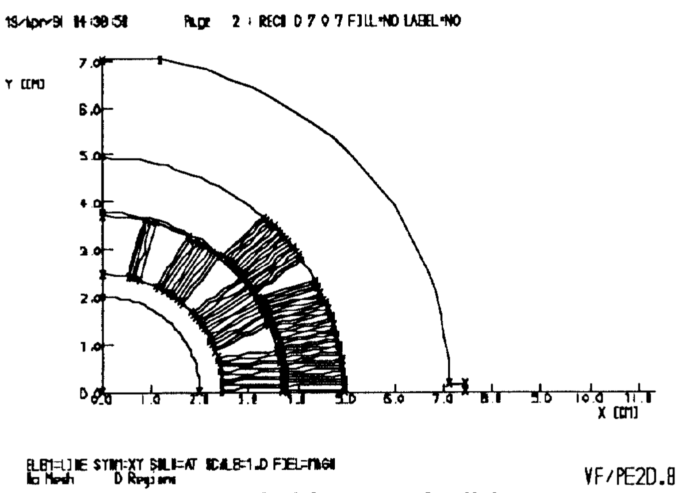

Figure 3. COP7 to PE2D link

A productivity enhancement evaluation between the CAE and manual approach has shown both time savings and reduction of design errors during modelling.

COP7 to ANSYS

A PREP7 file consisting of the keypoints, line segments and areas necessary to mesh the magnet coils is written by COPAL. At this stage, the surrounding collars, yoke, and shell can be added and a full ANSYS stress and deflection analysis performed. ANSYS is used to study the stress and deflections in the cold mass cross-section at four stages of magnet assembly and operation. The stages are - magnet collaring which involves prestressing the coils to study collar stresses and deflections; magnet assembly involving the addition of the yoke and stainless steel shell with an azimuthal stress added to the shell to simulate welding; magnet cooldown from 293K to 4K which can greatly change the stresses in the magnet due to the differences in the coefficients of thermal contraction for the various materials in the cold mass; and magnet energization involving the application of the Lorentz forces (calculated using the electromagnetic capabilities of ANSYS) to the coils.

The dipole CM coil solid model is shown in Figure 4. is comprised of some 720 keypoints and line segments.

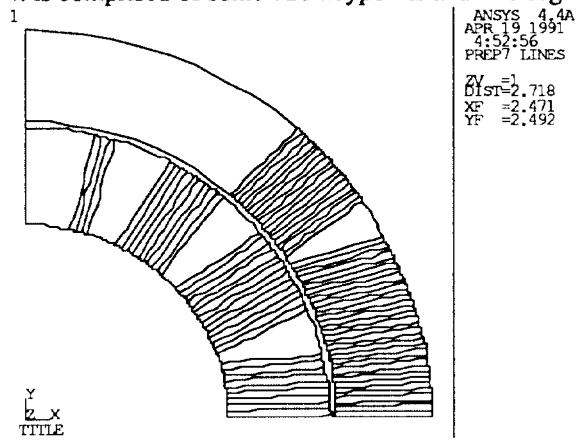

Figure 4. COP7 to ANSYS link

ANSYS to PE2D

The ANSYS to PE2D link is required among other reasons in order to study the effects of magnet cooldown and excitation resulting stresses on the field quality.

The code reads the original (cold) and deflected (hot) coordinate points of each block of coils as given by the ANSYS run and PE2D ".COMI" files are generated for cool, 2, 3, 4, and 6.5KA energization levels. Figure 5. shows the pre-processor output from PE2D as derived from ANSYS.

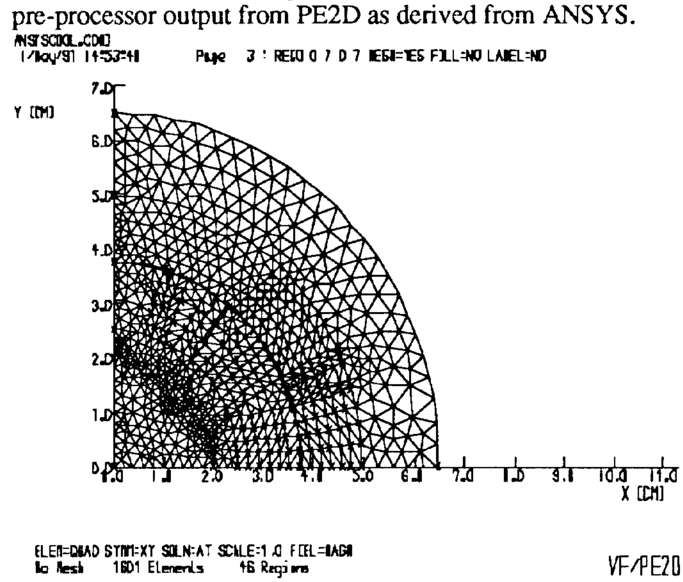

Figure 5. ANSYS to PE2D link

Table 1. below shows the results obtained from PE2D and demonstrates the effect of mechanical deflections on the coil harmonics for the collider dipole DSX201.

The cold field and harmonics variations are caused by the relative deflections of the different materials due to their different thermal contractions.

The mechanical deflections for the 2-6.5KA energization levels are due to the Lorentz forces which result in a horizontal outward and vertical inward movement of the coils, as can be seen in figure 6 below. Also infinite iron permeability was assumed for the yoke during the ANSYS calculation of the Lorentz forces.

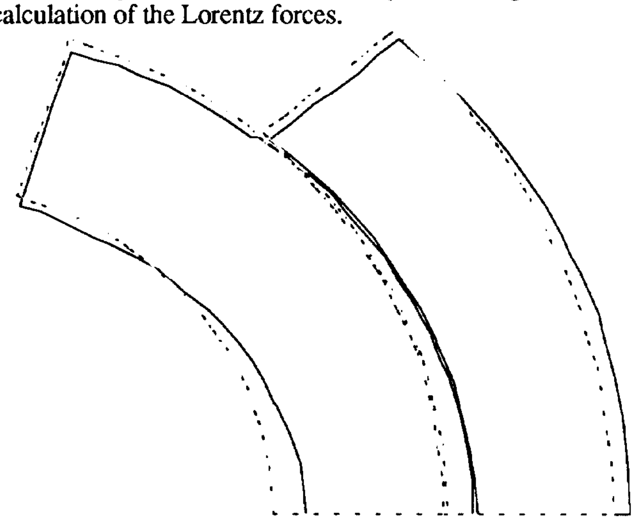

Figure 6. Coil Displacements due to Lorentz Forces. Dashed line represents the original shape and solid line represents the deflected shape.

Energization level	Field (Tesla)	Harmonics B2	Harmonics B4
room temp.	0	-1.58	-0.21
cold	0	1.13	0.01
2KA	2.14	-1.48	-0.22
3KA	3.21	-1.71	-0.23
4KA	4.27	-1.89	-0.22
6.5KA	6.94	-2.30	-0.35

Table 1. Field & Harmonic variations for DSX201

The harmonics are presented as parts in 10E-4 of the main field evaluated around a circle of one cm. radius [9], and are dimensionless. Also the field calculations have not been limited by the iron saturation.

CONCLUSIONS

The SSC project requires a significant number of magnet designs. A combined analysis and design code is required to complete this task. A substantial amount of work has been directed towards this goal, and this effort represents only the first attempt of a larger computer integrated project.

FURTHER WORK

The current computer hardware/software platforms for this CAE process have been VAX/VMS-Fortran and Macintosh with Tektronix type graphical capabilities emulator. Work is under way to migrate to a Unix X-windows workstation based operating environment for this and other CAE related activities. The front and back end software modules for COPAL will then have to be rewritten in C(++).

It is envisaged that these codes will be part of a broader SSCL/MSD effort to implement a CAE suite of programs for the design development and production of superconducting magnets within the SSCL and Industry.

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