SSCL-392

Paper to be presented to the 1991 ANSYS Conference, May 21 to 23, 1991 at the Pittsburgh Hilton and Tower in Pittsburgh. Pennsylvannia.

NONLINEAR STRESS ANALYSIS OF SUPERCONDUCTING DIPOLE MAGNET SHELL

K. K. LEUNG

SUPERCONDUCTING SUPER COLLIDER LABORATORY
DALLAS, TX

ABSTRACT

Dipole magnets are important parts of the Superconducting Super Collider. Optimum design of mechanical elements is essential in maximizing magnet reliability and minimizing quench occurrence. The major mechanical elements of the magnet are the skin, yoke and collar. These elements can be designed to prevent the undesirable effect:
(1) Reduction of the critical current density due to over-stressed coils. (2) Generation of frictional heat due to the micro motion of the coils under Lorentz forces. (3) Over - straining of the conductor insulation leading to short circuit.

A test result reveals excessive movement of the body yoke at the magnet end, and that quench develops mostly at the magnet end. Investigation of quench, which may be activated by restriction of the axial movement of the end coil assembly from end shell deflection is beyond the scope of this paper.

The proposed end shell design attemps to enhance the magnet reliability and safety by minimizing the local bending stresses at the end skin. In this paper, analytical results and propositions to tackle these issues are presented. The optimum design is to minimize coil deflections without overly stressing the coils. However, the range of optimization must be within the low cycle fatigue limit of the skin, and specifically in the skin seam weld zone. The present analysis is performed in finite element analysis method. The ANSYS finite element code was used to analyze the end shell.

INTRODUCTION

The design guidelines for the dipole magnet skin are compiled as follows: (1) To provide axial and radial pre-loads to the yoke and collared coil assembly in order to control the conductor deformations, stresses and movements. (2) To perform as a pressure vessel. (3) To serve as a girder for registering the coil and yoke assemblies in maintaining a precise mechanical magnet center under significant loadings.

A low cycle fatigue stress limits must be observed for a magnet shell (skin) design to realize long term operational reliability. The critical bending stresses under pre-load and thermal load are found in the end skins of the dipole magnet. These stresses can be minimized by utilizing an end yoke extending from the body yoke to the end plate. The elastic skin pre-stress is produced in two steps. (a) Mechanical pre-stress. Apply a "skin press" to pre-load the skin to about 30 ksi, (b) Thermal pre-stress. Design geometrical, elastic and thermal properties on the yoke, skin and collar to obtain optimum coil stress.

Plastic stress in the skin seam weld zone is employed to obtain a uniformly distribution of stress for the dipole magnet. Test result reveals that the plastic range is establiseded along the longitudinal seam welds in the skin. The local plastic zone is actuated by thermal contraction of the seam weld of the pre-stressed skin

The total pre-stresses on the shell are optimized to overcome the Lorentz forces as developed by the magnet in operational condition. The optimization, however, was performed on a 2-D section model which details the yoke and collared coils assembly with various gaps elements. It was found [1] that the magnitude of the skin stresses in the end shell increases by nearly 100% of the 2-D section. It can be expressed by an equation as "$\sigma = 1.98\, E\, \Delta T \times \Delta\alpha$" This equation suggests that the end skin stresses are independent of the skin thickness.

Past studies indicate that the critical skin stresses are concentrating in the area where the laminated body yoke "fall" off to the magnet ends. Various design modifications of the end skin [2] were proposed. The present analytical results indicates that using an end yoke with suitable thermal property can effectively reduce the stresse

RESULT OF 3-D END SKIN STRESS ANALYSIS

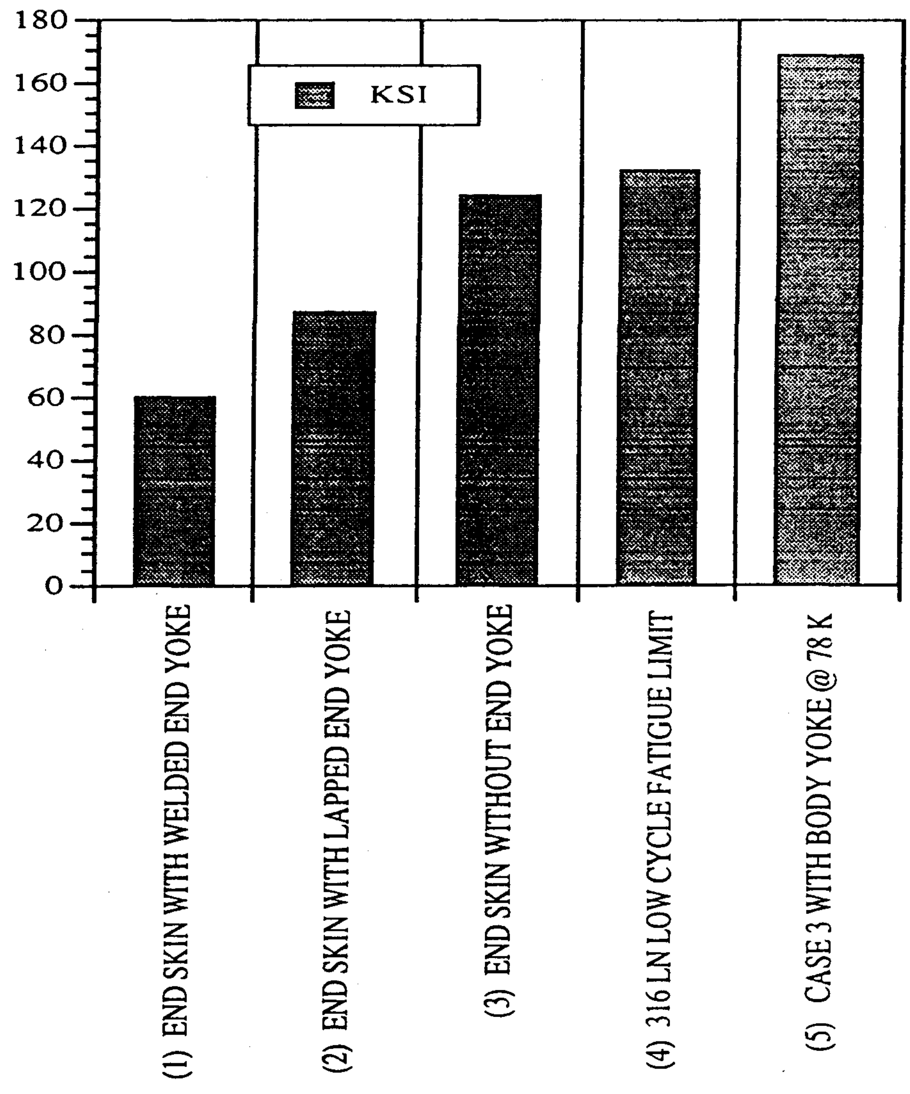


FIGURE 1 SUMMARY OF MAXIMUM END SKIN STRESSES

ANSYS 3-D FINITE ELEMENT MODEL

Refer to Figure2 for a description of the end shell model. The analysis was performed using the ANSYS code (4.4 a +) on a VAX 6420 in the SSC Laboratory. The skin was modeled with STIF63 shell elements. The end yoke was modeled with two layers of STIF73 solid element with six degrees of freedom (DOF) in each node to ensure displacement compatibility with the skin. The top layer of the end yoke element can be transformed to STIF52, a nonlinear interface element used for interference fit, gap and sliding frictions inside the end skin The same layer can be modeled as weldment to determine the spot welded connection stress. The dynamic stress and stress wave propagation through a bi-metallc joint between the skin and yoke subjected to Lorentz force or quench loads, (a sharp rise-time transient loads), can also be examined by the present model in future because DOF compatibility between STIF73 and STIF63 .

Mechanical pre-stress on the skin was input with radial pressure on STIF63 as 1000 psi. This loading can be reversed in direction as burst load to study pressure vessel stress in the end skin. Thermal loads are input with initial temperature at 300 K and coodown to 4K.

Displacement boundary conditions of the skin and end yoke in a quarter skin end model are coded along x-z and y-z plane with the D command to account for the free radial directional movement of the skin. Displacement boundary conditions of the coil assembly was modeled in such a way that the coil assembly will produce exactly the same amount of thermal axial load to the end plate as obtained from the test.

The body yoke was modeled with areas cut-out to represent the helium tube and bus cavity to account for local stiffeness effect on skin stress. The total number of elements is 3280, of which 620 are used for the skin. Figure 2 is the section view of the end shell assembly of the collider dipole magnet. Figure 3 is the finite element model of the end shell assembly as shown in Figure 2. Both the end plate and the yoke are represented by circular plates.

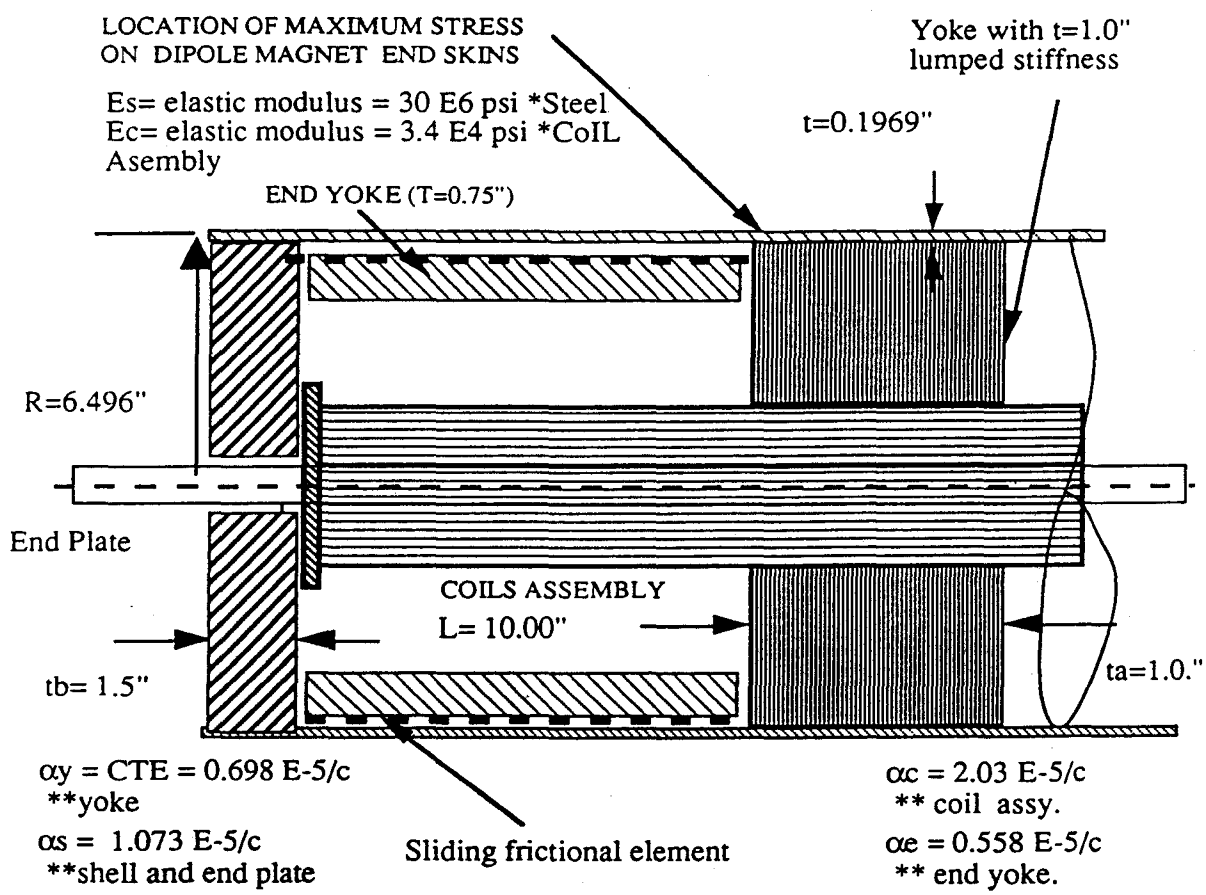


Figure 2. 50 mm dipole magnet end skin design with end yoke

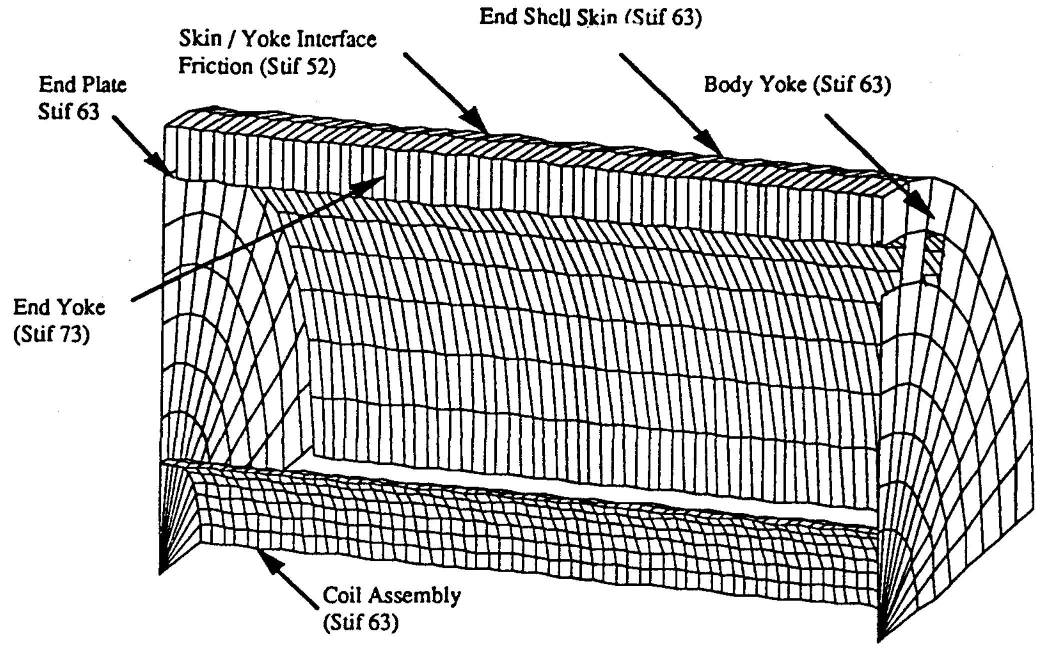


Figure 3. Fnite Element Model Of End Skin Assembly

2-D FINITE ELEMENT MODEL

The 2-D nonlinear elastic stress analysis of the dipole is primary for studying of coils stresses which arebasically plane stress. The 2-D model can not predict the skin stresses beyond the body yoke because bending of the skin in the longitudinal direction of the shell. The end shell stresses which are located outside the body yoke are approximately increased by a factor of two to the skin stress in this 2-D section .

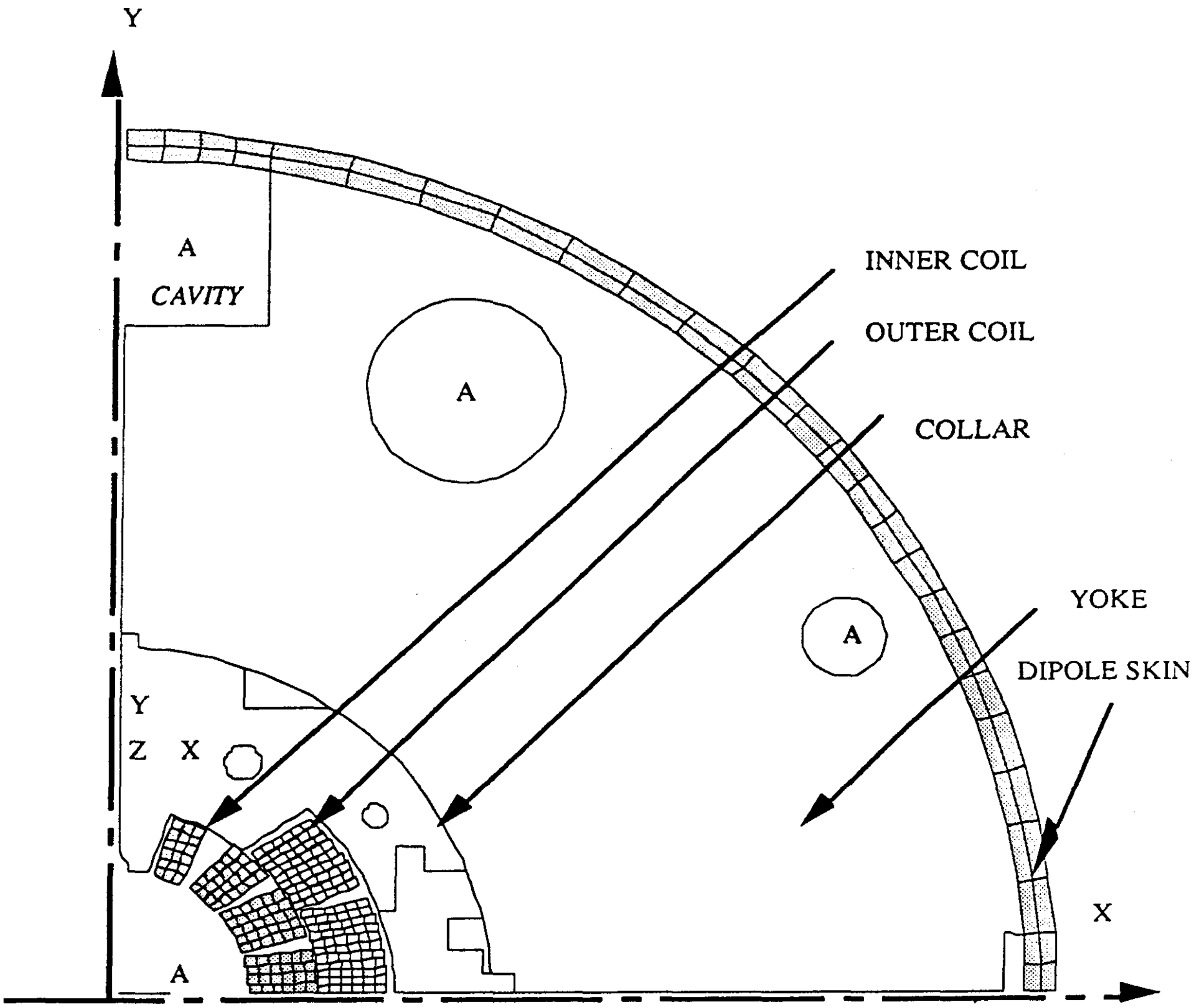
The dipole magnet assembly is subjected to internal forces from magnetic, thermal, and mechanical loadings as well as external forces from supporting strut, tie-rods, and discontinuous stress from reinforcements. The external forces are not considered in the present study.

The coil is modelled as an temperature independent, linear elastic material with no friction considered in any of the interfaces. The maximum skin stresses ascend to 45 kSI at the skin / yoke interfaces. Local bending stresses from the bus cavity are account for 15 KSI of the total skin stresses. These local bending are eliminated from the dipole skin by redesigning the cavity 0.75 in. inward (to the center). The 2-D finite element model and the the skin stresses under mechanical, thermal and magnetic forces areshown in Figure 4, and 5.

From thr result of 2-D anlysis as shown in Figure 5, One can see that the maximun skin stress ascend to the maximum value as the whole assembly is cooled to 4.2 K. The huge Lorentz forces as generated by the cuurent conductors are exceeding 100 tons per meter. The forces are acting on the two halves of the dipole coils which repel each other. In the case of vertical yoke configuration the yoke acts a spacer and transmitting the Lorentz forces to the skin. In the horizontal design configuration,the yoke acts as a deep curve beam and will prevent some of the Lorentz forces to go to the skin. Considering the coils for the most uniform stresses distribution as the design specification, the vertical split yoke design configuration is a better design.

The 2 D collider dipole magnet section is modeled with Stif 13. The magnetic field designated as (A) is the air space which is required for magnetic analysis.

The areas from top to bottom are electrical bus cavity, Liquid helium bypass, hole for tie rod and hole for beam tube which hold the collider beam. There are two layers of gap elements. The gaps between the skin to the yoke as well as between the collar to the yoke is designed to be line to line fit at operating condition. A sucessful design of the collider dipole magnet can be summaried in one line, that is, a practically perfect circular coil assembly with the collar line to line fit



Multi field Elements STIF 13 are used to modeled the 2 - D section.
Elements at location A for air are omited in the figure for clarity.

FIGURE 4. FINITE ELEMENT MODEL FOR DIPOLE MAGNET 2 - D SECTION

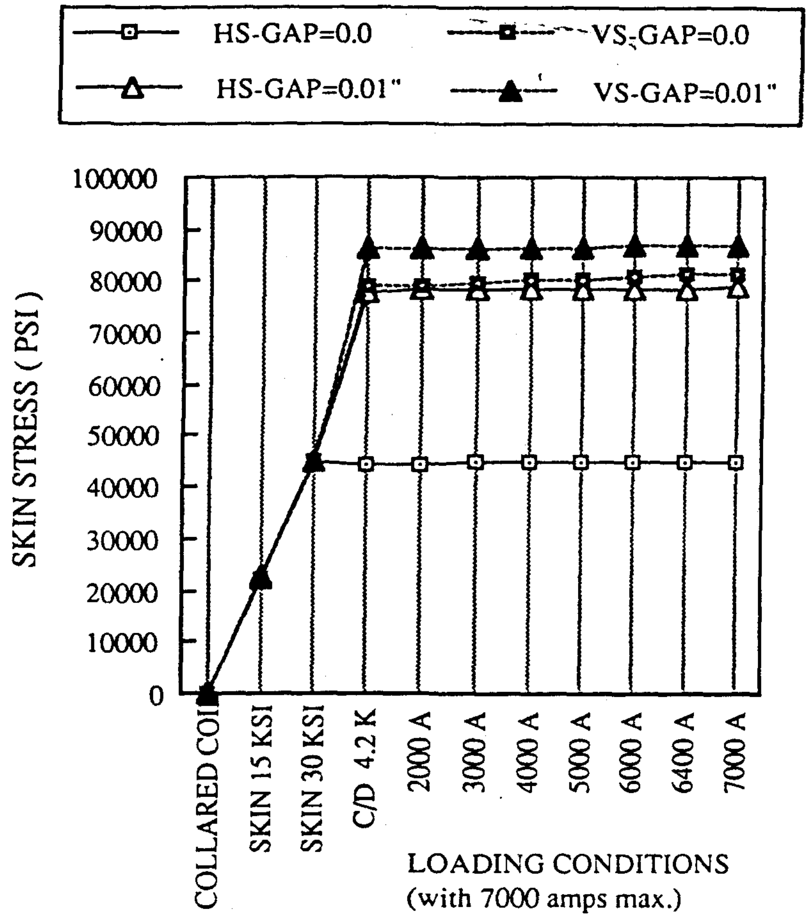


FIGURE 5. SUMMARY OF 2-D SECTION SKIN STRESSES FOR DIFFERENT YOKE/GAP DESIGN

REFERENCES

1. Superconducting Super collider Laboratory Report, SSCL - N 702, 1990

2. Superconducting Super collider Laboratory Report, SSCL - N 705, 1990

3. Superconducting Super collider Laboratory Report,
Site-Specific Conceptual Design. July 1990.

* Superconducting Super collider Laboratory Operated by Universities Research Association under contract with the U.S. Department of Energy.

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U. S. Department of Energy, under Contract No. DE-AC02-89ER40486.