Fermilab

SSC DETECTOR SOLENOID DESIGN NOTE #107

TITLE: Finite Element Analysis of Shear Stress between Conductor and Support Cylinder Due to Magnetic Loads in an Air Core Solenoid

AUTHOR: Bob Wands and Jim Krebs

DATE: Dec. 26, 1989

Fermilab

EAR-3
December 26, 1989

Finite Element Analysis of Shear Stress Between Conductor and Support Cylinder Due to Magnetic Loads in an Air Core Solenoid

Bob Wands
Jim Krebs

Introduction

The air core solenoid designs for an SSC solenoid produce large axial forces, which result in shear stresses in the epoxy bond between the conductor and the support cylinder. The purpose of this work is to model the conductors and support cylinder with sufficient refinement to represent individual conductor turns, and apply the magnetic loading turn-by-turn to accurately model the stresses in the conductor-support cylinder interface. Advantage is taken of the non-linear elastic material behaviour option in the ANSYS program to use realistic stress-strain data for the high-purity aluminum conductor stabilizer material.

The Finite Element Model

The 1.8 m, 2.0 T air core solenoid was modeled with the I-deas program using four 4-node quadrilaterals to model each of the 690 turns in the four-meter half-length of the solenoid. This mesh density placed a node at the center of each conductor turn, which could then be loaded with the appropriate magnetic forces.

Magnetic forces were applied by interpolating the conductor field solution from an ANSYS analysis(1) to each nodal location in the refined mesh, and calculating the force as I X B, where I = 10000 A. The forces were written to a file in the appropriate format for input to the Ideas program. As a check of the method, the sum of the forces input to Ideas was compared to the sum of the forces calculated by ANSYS, and found to be within 2% of the ANSYS values.

The conductor and support cylinder dimensions used are shown Fig. 1, and were taken from (1) for the ACS-A geometry with 10000 A. The loading of the indicated node in the mesh is equivalent to a load distributed over the shaded area shown, and in this sense the stresses near the point of load application will differ from the real stresses at the superconductor. However, the effect of this loading on the shear stresses between the conductor and the support cylinder should be negligible.

The I-deas mesh was translated into an ANSYS input file, and the ANSYS non-linear elastic material property option was used to characterize the conductor material. This option allows for the low yield strength of the high purity aluminum stabilizer in comparison with the support cylinder. The stress-strain curve used is shown in Fig. 2, and was obtained from (2)

Results

The shear stress between the coil and the support cylinder is plotted along the four meter half-length of the solenoid in Fig. 3. The maximum shear stress was 105 psi, and occurs about 18 cm (7 inches) from the end of the solenoid. At the solenoid collaboration meeting at ANL on November 16-17, data was presented showing epoxy bond breaking strengths in shear of approximately 2800 psi. Therefore, the stresses found in this analysis are well within a reasonable working stress range for a practical epoxy bond.

The hoop stress in the conductor and the support cylinder is shown in Fig. 4. The conductor produces far less stress than the support cylinder, as expected from the stress-strain relationship for the high-purity aluminum stabilizer. The actual level of maximum stress is 6100 psi, and corresponds to a conductor strain of 0.0015 (0.15%), which is greater than the desired level of 0.1%. This can be remedied by increasing the support cylinder thickness.

Conclusion

The results of this model, which accurately represents the stabilizer material non-linearity and the distribution of magnetic forces on the individual conductor turns, show that the shear stresses between the conductor and the support cylinder are acceptable working stresses for the epoxy bond between these components.

References

1. Wands, B.,'Comparison of Air Core and Iron Return Solenoid Magnetic and Structural Characteristics', SSC Detector Solenoid Design Note #106, December, 1989

2. Fast, R., et. al., Design Report for an Indirectly Cooled 3-m Diameter Superconducting Solenoid for the Fermilab Collider Detector Facility, Fermilab TM-1135, October, 1982

SDRC I-DEAS 4.1: Pre/Post Processing 27-DEC-89 10:07:30

DATABASE: DETAIL CONDUCTOR STRESS MODEL
VIEW : No stored VIEW
Task: Post Processing
Model: 1-FE_MODEL1

UNITS : IN
DISPLAY : No stored OPTION
Associated Workset: 1-WORKING_SET1

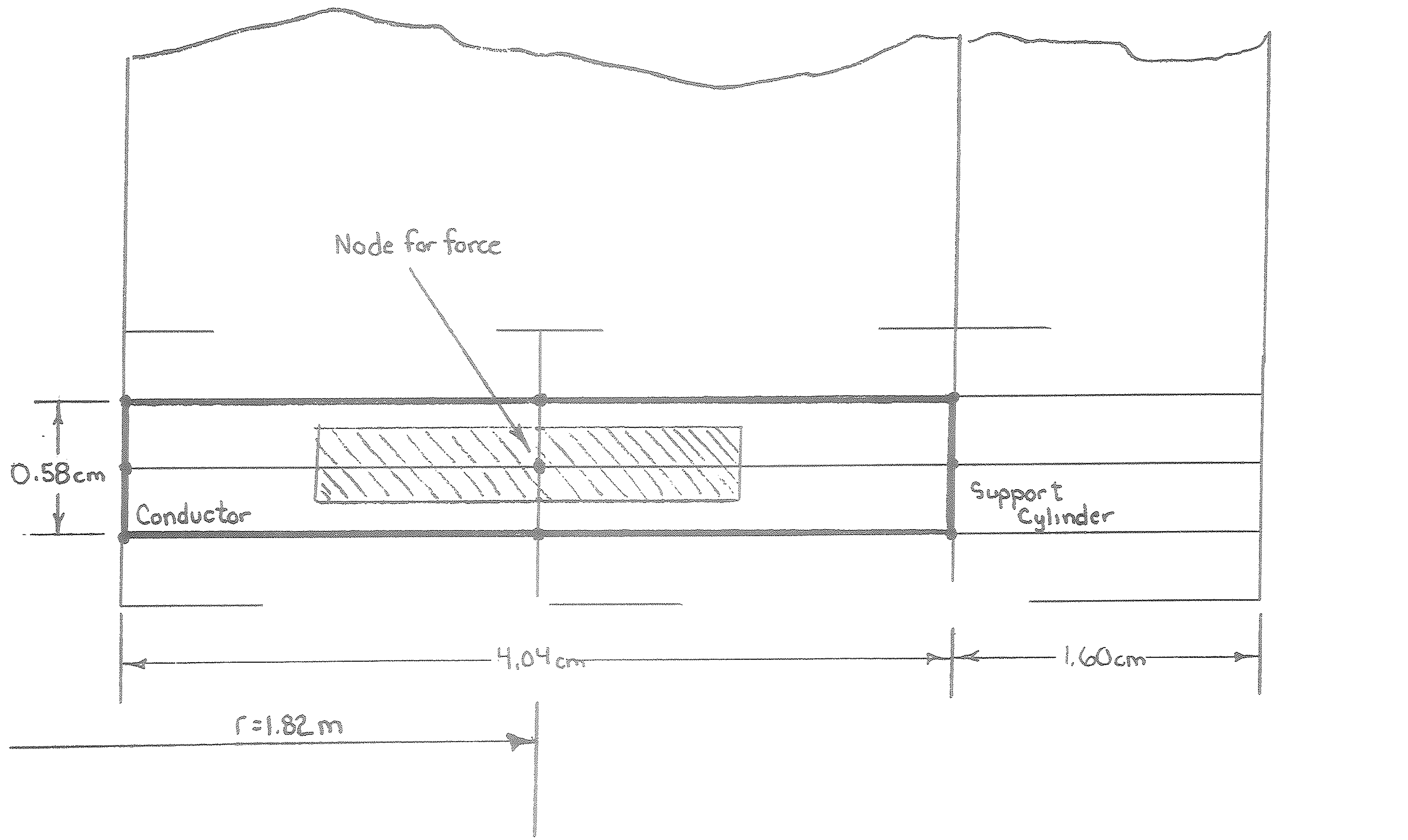
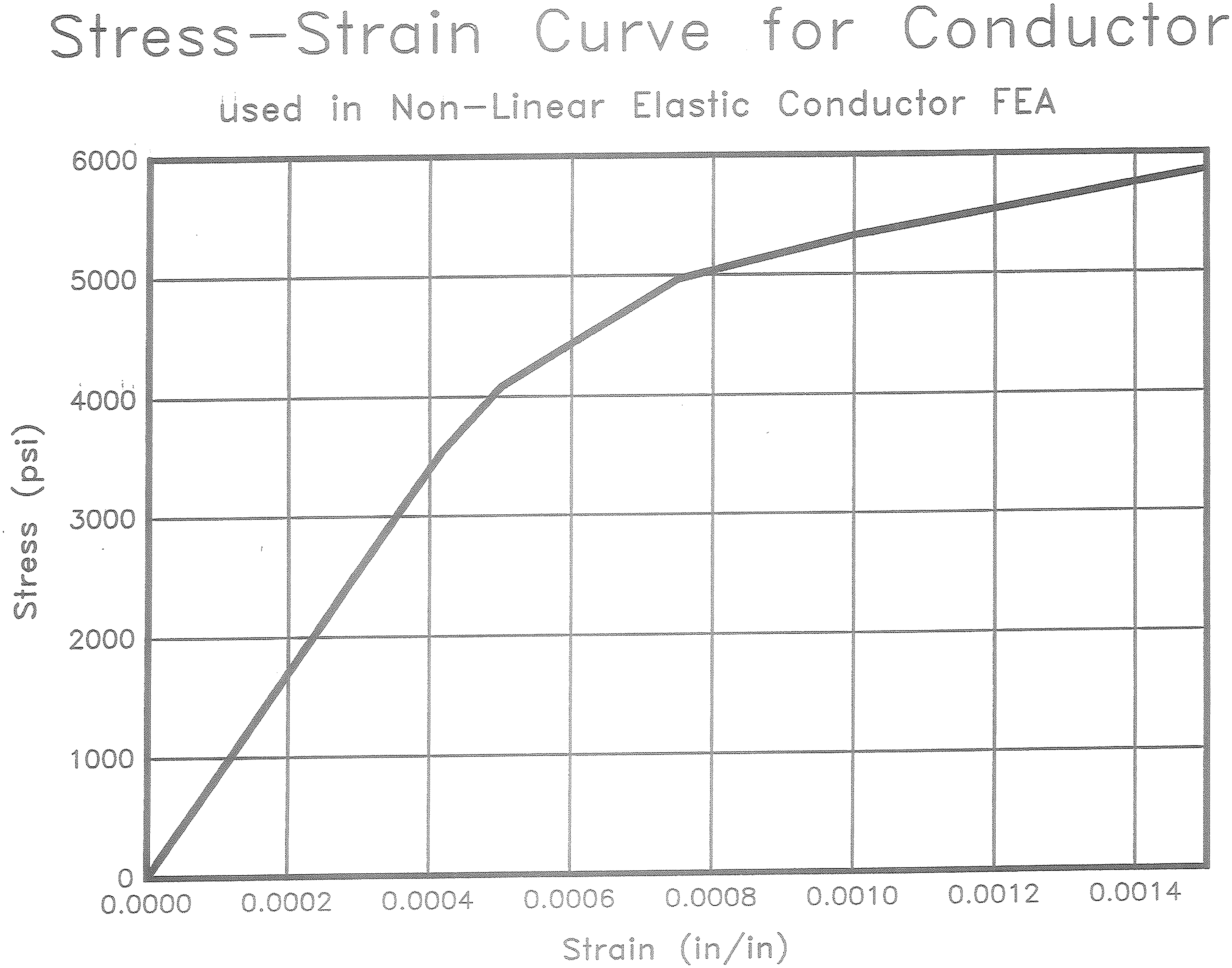


Fig. 1. Conductor and Support Cylinder Dimensions

Fig. 2.



Stress-Strain Curve for Conductor
used in Non-Linear Elastic Conductor FEA
6000
5000
4000
3000
2000
1000
0
Stress (psi)
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
0.0012
0.0014
Strain (in/in)

Fig. 3.

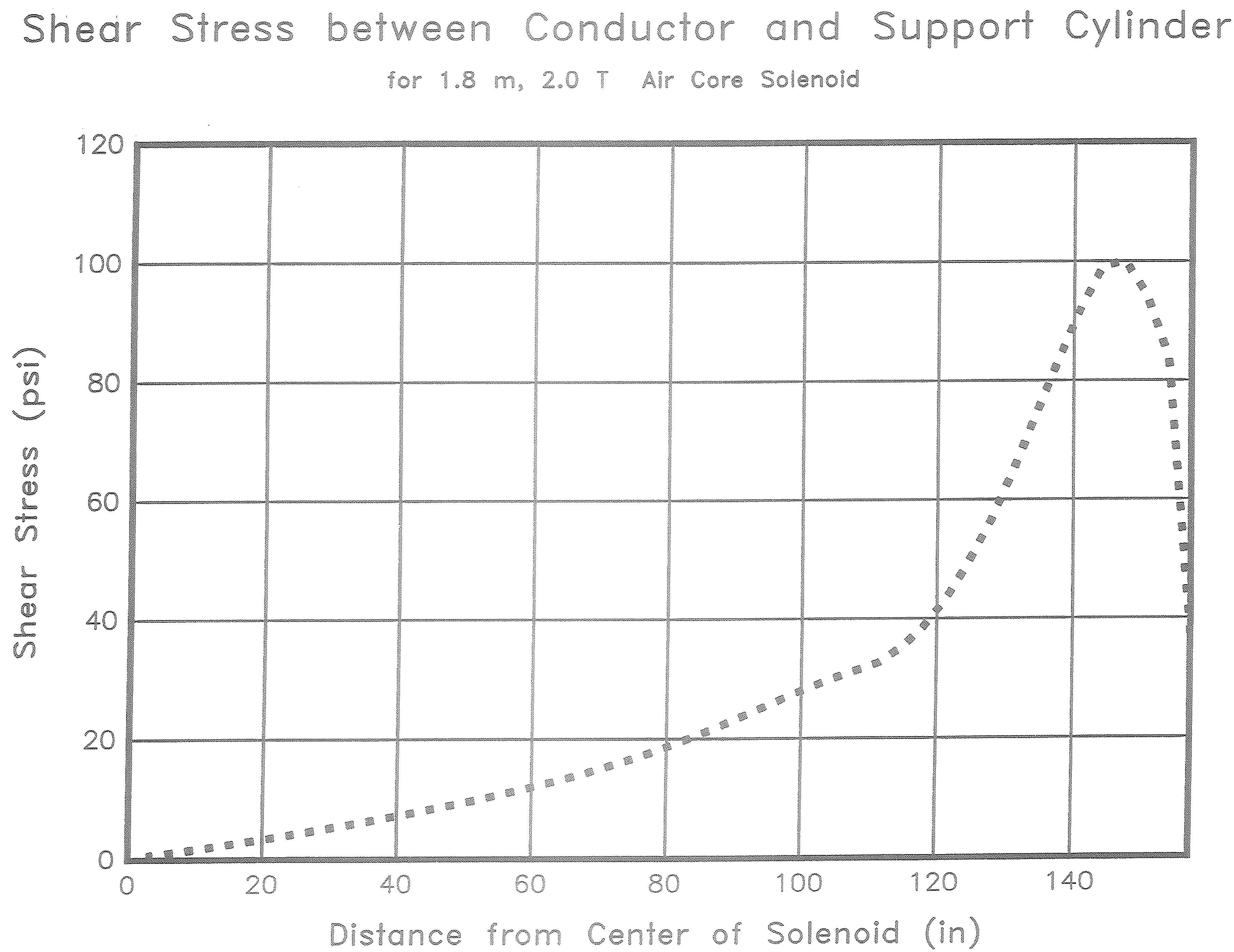
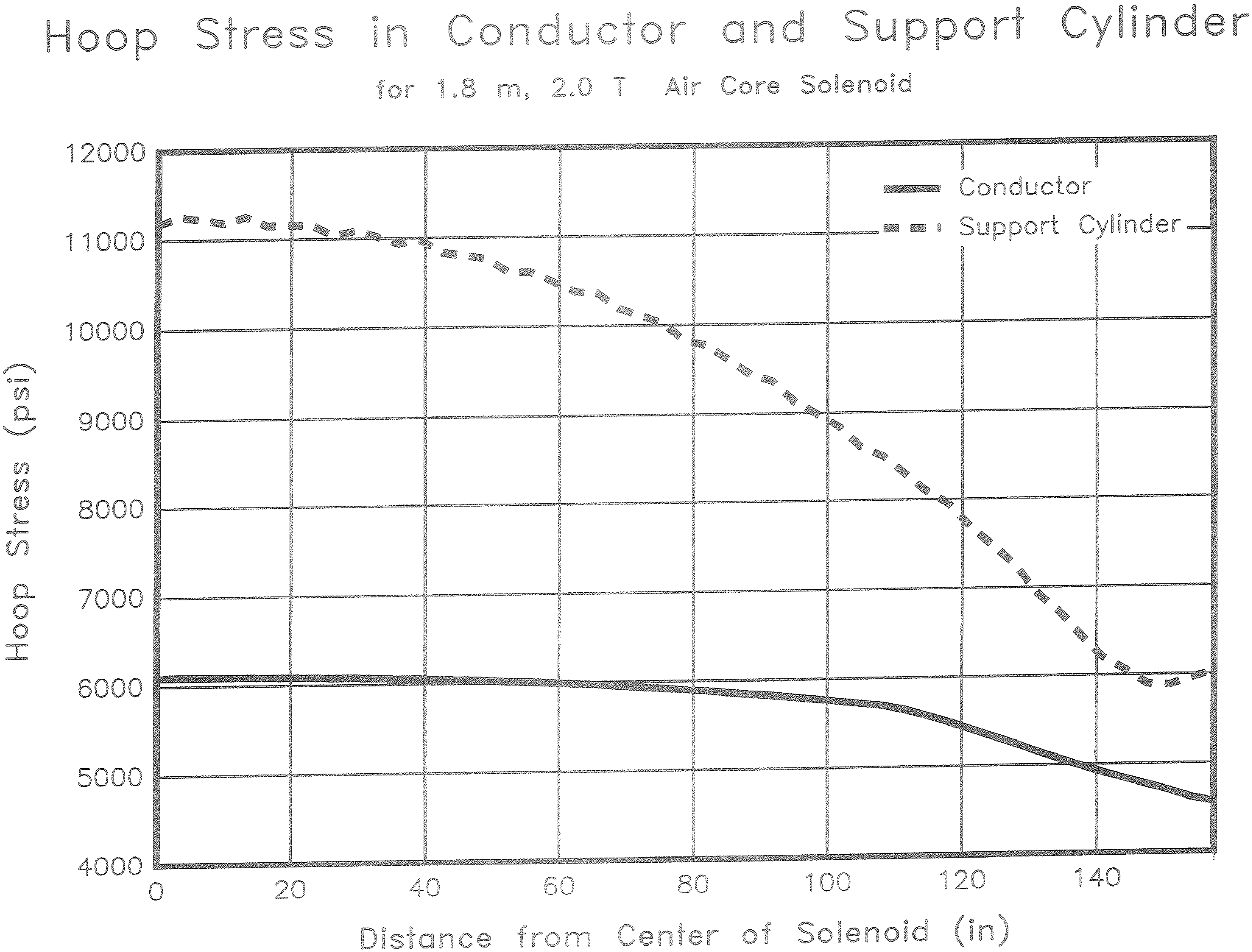

Shear Stress between Conductor and Support Cylinder
for 1.8 m, 2.0 T Air Core Solenoid
Shear Stress (psi)
0
20
40
60
80
100
120
0
20
40
60
80
100
120
140
Distance from Center of Solenoid (in)

Fig. 4.


Hoop Stress in Conductor and Support Cylinder
for 1.8 m, 2.0 T Air Core Solenoid
Conductor
Support Cylinder
12000
11000
10000
9000
8000
7000
6000
5000
4000
Hoop Stress (psi)
0
20
40
60
80
100
120
140
Distance from Center of Solenoid (in)