EAR-29
8-12-91

SDC Design Note 141

A Truss Support System for the SDC Superconducting Solenoid

Jim Krebs

Introduction

The purpose of this work is to determine a feasible method of supporting the SDC superconducting solenoid inside its vacuum chamber. The cryostat assembly is located internal to the barrel electromagnetic and hadronic calorimetry. This geometry requires that both the coil and the cryostat be "thin" in terms of physical thickness and radiation and absorption lengths. Greater transparency may be achieved through the use of low absorption structural materials for the outer vacuum shell. One function of the support system is to ease the mechanical strength constraints on the outer vacuum shell by transmitting all of the gravitational and electromagnetic loads from the 4.2 K degree coil package directly through the annular bulkheads of the vacuum chamber which are at 300 K degrees.

The chimney end of the coil incorporates 32 support rods that form a dual function trussed support system that is designed as a load path for all of the axial decentering force and half of the radial decentering force. The remaining radial decentering force is distributed on the opposite side of the coil using a single function truss support that has a sliding connection at the coil to allow for thermal contraction in the direction of the solenoid axis. Therefore, no tension preloading or adjusting of the support rods is necessary after final assembly.

Each of the support rods is assumed to be a carbon fiber filament wound composite with titanium 6al-4v integrally wound threaded fittings on both ends. Also, the rods incorporate radiation intercepts at 77 K degrees and 4.2 K degrees to minimize the amount of external thermal energy introduced to the coil due to conduction and pinned spherical ball bearings on both ends to minimize the development of bending moments under load conditions.

The metallic end components mentioned hereafter are sized for comparison using mechanical properties at room temperature. The maximum allowable stresses are determined by the lower of 2/3 minimum yield stress or 1/4 minimum ultimate stress according to the ASME Boiler and Pressure Vessel Code, Section VIII, Div. 1. The allowable shearing stress is determined as 1/2 the allowable tensile stress.

General Assumptions (All values at 300 K degrees except where noted)

Mean radius of current sheet (4.2 K degrees)	71.26 inches (1810 mm)
Length of current sheet (4.2 K degrees)	299.22 inches (7600 mm)
Radius of warm support location	76.50 inches (1943 mm)
Radius of cold support location	75.25 inches
Axial length of vacuum chamber	314.96 inches (8000 mm)
Conductor radial thickness (4.2 K degrees)	1.73 inches (44 mm)
Bobbin radial thickness (4.2 K degrees)	1.22 inches (31 mm)
Number of truss support points per side	16

General Assumptions (continued)

		Reference
Modulus of elasticity (carbon fiber)	27,000 ksi	
Minimum yield stress (carbon fiber)	100 ksi	
Maximum allowable tensile stress (carbon fiber)	52 ksi	
Ultimate strength (inconel 718)	180 ksi	MH
Minimum yield stress (inconel 718)	150 ksi	MH
Radiation length (inconel 718)	16.4 mm	DN-126
Minimum yield stress (titanium 6al-4v)	135 ksi	MH
Ultimate strength (titanium 6al-4v)	145 ksi	MH
Radiation length (titanium 6al-4v)	37.2 mm	DN-126
Maximum yield stress (aluminum 2219-T851)	51 ksi	MH
Ultimate strength (aluminum 2219-T851)	63 ksi	MH
Radiation length (aluminum 2219-T851)	79.5 mm	DN-126
Minimum yield stress (aluminum 7075-T6)	66 ksi	MH
Ultimate strength (aluminum 7075-T6)	75 ksi	MH
Radiation length (aluminum 7075-T6)	90 mm	
Ultimate strength (beryllium copper 172)	175 ksi	MH
Specified minimum yield stress (beryllium copper 172)	150 ksi	MH
Radiation length (beryllium copper 172)	14.5 mm	DN-126
Weight of cold mass	44000 pounds	(20 tonnes)

The Finite Element Model

A one half finite element model was created using the ANSYS general purpose finite element program. Figure 1 is a view of the finite element model as if one were looking down the x axis The support rods are represented by stif 8 3d spar elements. The coil assembly is defined using stif 63 quadrilateral shell elements. The total thickness of this assembly is the sum of the conductor thickness plus the bobbin thickness. The model consists of 714 nodes and 672 elements. The maximum wavefront is 150. Three load cases were run:

A. A thermal cooldown of the coil from 300 degrees kelvin to 4.2 degrees kelvin. No electromagnetic or gravitational loading.

B. Estimated radial decentering forces totalling 132,000 pounds (3 x cold mass = 60 tonnes) for a one inch cold mass radial displacement (DN-149).

C. Estimated axial decentering forces totalling 145,300 pounds (66 tonnes) for a one inch cold mass axial displacement (DN-149).

Cooldown Analysis

Figure 2 is a stress plot of the cold mass after a thermal cooldown from 300 degrees kelvin to 4.2 degrees kelvin. No electromagnetic or gravitational loading is present. The figure indicates that the truss support system allows a stress free cooldown of the cold mass. The support rod axial forces are also negligible.

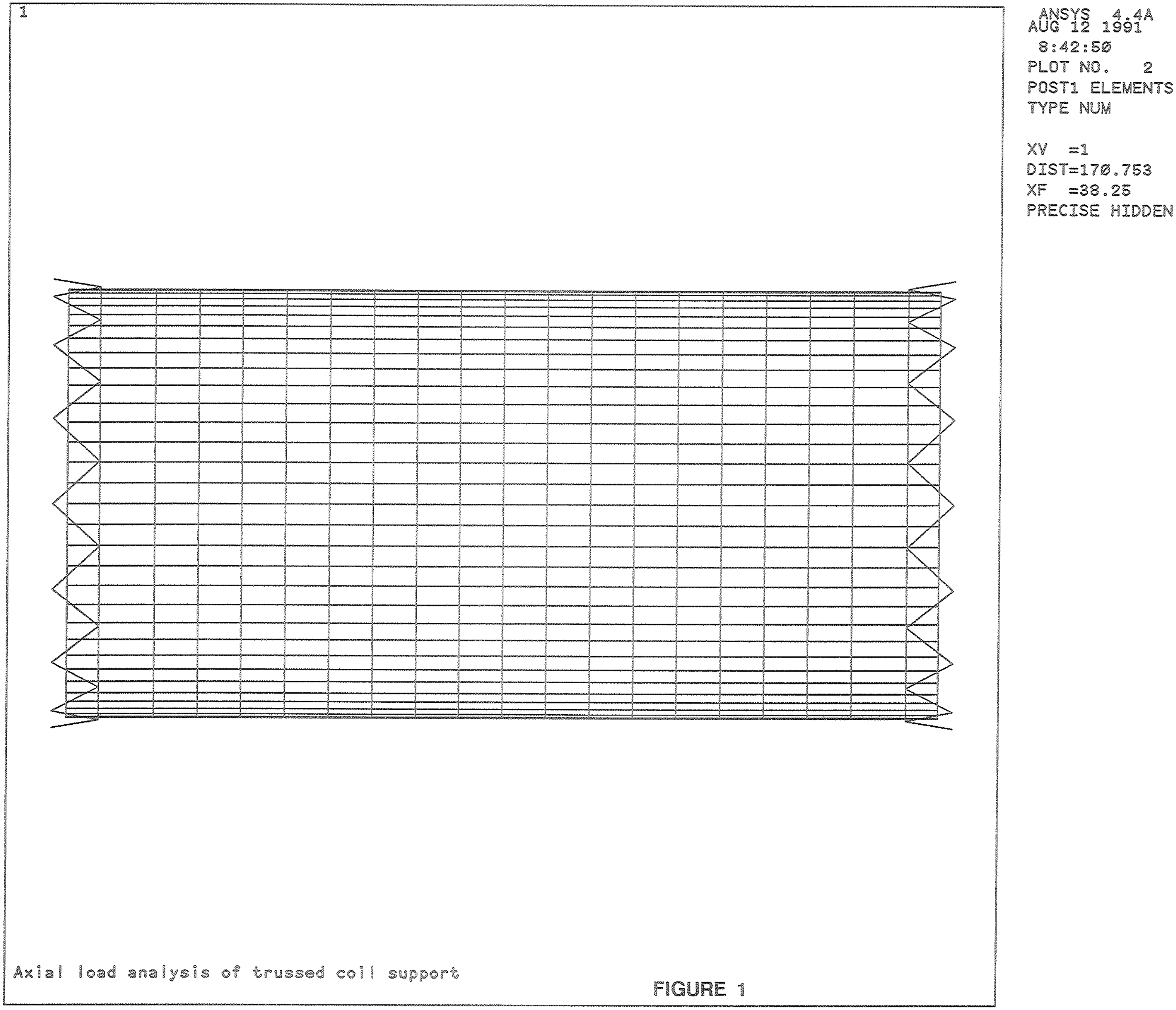
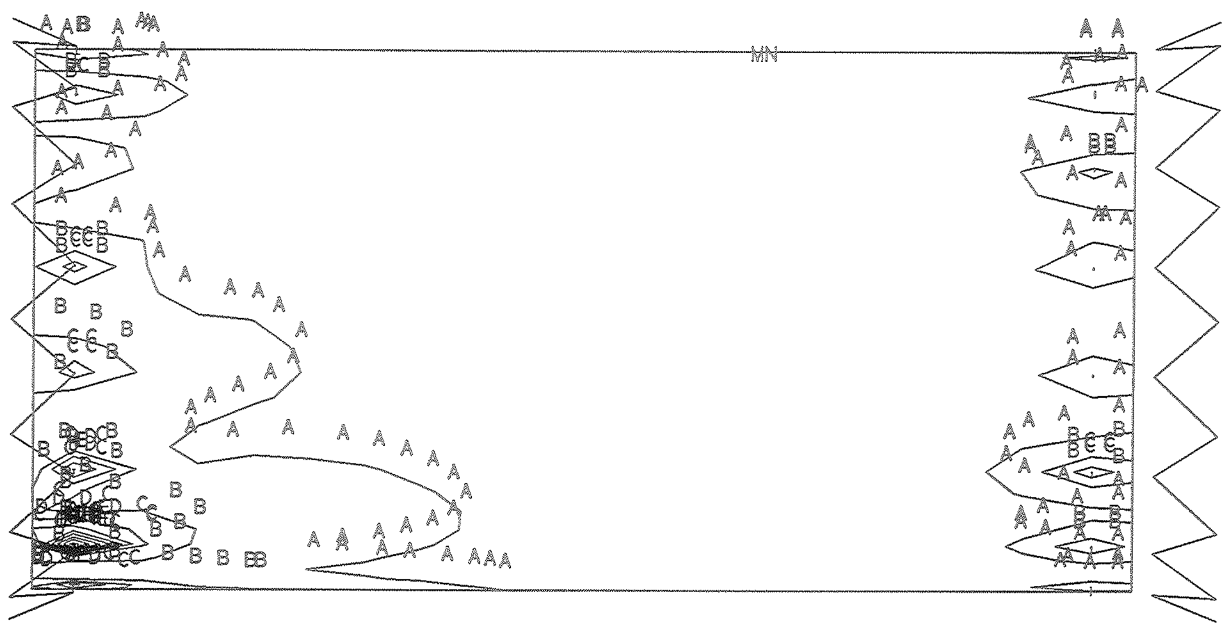

1
ANSYS 4.4A
AUG 12 1991
8:42:50
PLOT NO. 2
POST1 ELEMENTS
TYPE NUM
XV =1
DIST=170.753
XF =38.25
PRECISE HIDDEN
Axial load analysis of trussed coil support

FIGURE 1

1



ANSYS 4.4A
AUG 12 1991
10:52:44
PLOT NO. 1
POST1 STRESS
STEP=1
ITER=1
SI (AVG)
BOTTOM
DMX =1.262
SMN =0.386E-05
SMX =0.002442
SMXB=0.003219

XV =1
DIST=170.753
XF =38.25
EDGE
A =0.139E-03
B =0.410E-03
C =0.681E-03
D =0.952E-03
E =0.001223
F =0.001494
G =0.001765
H =0.002036
I =0.002307

Cooldown analysis of trussed coil support

FIGURE 2

Support Rod Axial Forces Due to Magnetic and Gravitational Forces

Figure 3 is a graph of axial force magnitudes in the support rods as a function of the truss axial connection location on the coil. Maximum axial and radial coil loading is assumed. The rod force components in the chimney end supports due to axial and radial coil loading and the rod force in the slide supports all vary with axial connection location. The minimum axial force value in the chimney end support rods occurs with a connection point at approximately 3550 mm axially from the coil center. This value is 12300 pounds. The corresponding force that is induced in the supports on the other end is 6100 pounds. Forces induced by the friction in the slide mechanism are disregarded. The length of the truss support rod for this geometry is approximately 22.250 inches from warm pin center to cold pin center.

Rod Size - Carbon Fiber Composite Truss Support

Since the direction of the axial decentering forces cannot be determined with reasonable certainty, the truss support rods on the fixed (chimney) end must be designed as tensile/compressive members. According to the AISC Manual of Steel Construction, the maximum allowable compressive stress in an axially loaded compression member is determined by:

$$F_a = \frac{\left[1 - \frac{(Kl/r)^2}{2C_c^{\,2}}\right]F_y}{\frac{5}{3} + \frac{3(Kl/r)}{8C_c} - \frac{(Kl/r)^3}{8C_c^{\,3}}} \qquad \text{where} \qquad C_c = \sqrt{\frac{2\pi^2 E}{F_y}}$$

and nomenclature is defined as follows:

Fa = Axial compressive stress permitted in a prismatic member in the absence of bending moment, in psi

K = Effective length factor for a prismatic member (Equal to 1.00 for this application)

l = Actual unbraced length of member, in inches

r = Governing radius of gyration, in inches

Cc = Column slenderness ratio separating elastic and inelastic buckling

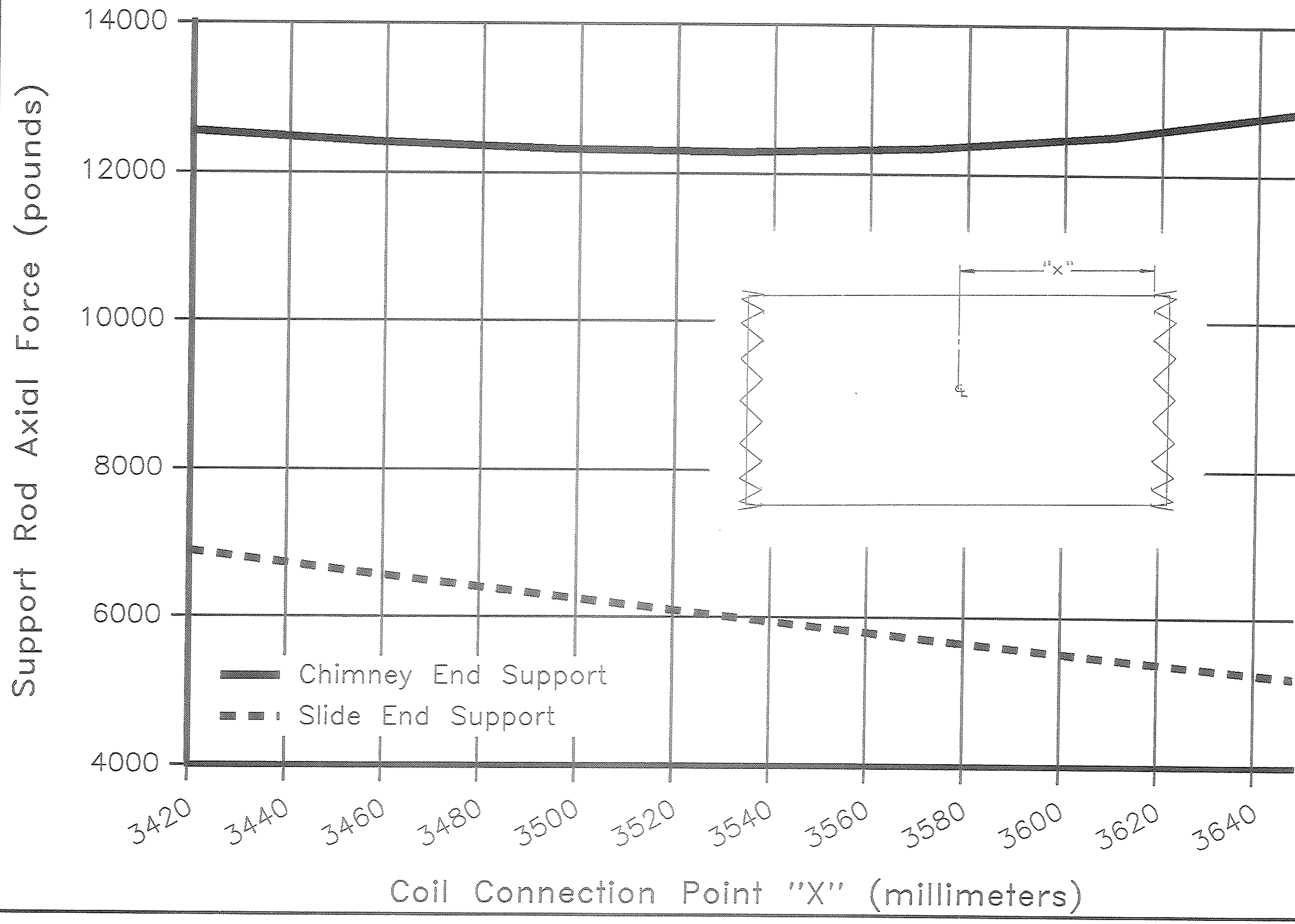
Fy = Specified minimum yield stress of the type of material used, in psi

E = Modulas of elasticity for type of material used, in psi

Therefore, the maximum allowable compressive stress for a 1.250" diameter x .125" thick wall support rod is calculated to be:

$$\frac{[1 - (55.625)^2/2(73)^2]\ 100000}{5/3 + 3(55.625)/8(73) - (55.625)^3/8(73)^3} = 37{,}400 \text{ psi}$$

Figure 3



14000
12000
10000
8000
6000
4000
Support Rod Axial Force (pounds)
Chimney End Support
Slide End Support
"X"
3420
3440
3460
3480
3500
3520
3540
3560
3580
3600
3620
3640
Coil Connection Point "X" (millimeters)

The actual direct stress on the rod is:

$$(12300 \text{ lb.})/(.442 \text{ in.}^2) \quad = \quad 27{,}850 \text{ psi}$$

It is important to realize that this method of formulation was developed for steel construction applications only. Thus, the 37,400 psi allowable stress will supply a basis to determine the APPROXIMATE cross section of the rod. Actual optimized cross section dimensions should be determined by an engineering firm with experience in the design and manufacture of carbon fiber filament wound composite assemblies.

Pin Diameter (See Figure 4)

The rod pins are in double shear. Therefore, the cross sectional area, a, of the pins are determined by:

$$\frac{P/2}{Fs}$$

where nomenclature is defined as:

P = Maximum axial force in the composite support rod

Fs = Maximum allowable shear stress in the pin

and the maximum allowable shear stress is equal to 1/2 the maximum allowable tensile stress. Thus, the pin diameter, d, is determined by:

$$2\sqrt{\frac{a}{\pi}}$$

Pin Diameter (Titanium 6al-4v)

For titanium 6al-4v the cross sectional area of the pin is determined to be:

$$[(1/2)(12300 \text{ lb.})]/(1/2)(130000/4 \text{ psi}) \quad = \quad .379 \text{ in}^2 \text{ or } .695'' \text{ diameter.}$$

Pin Diameter (Inconel 718)

For inconel 718 the cross sectional area of the pin is determined to be:

$$[(1/2)(12300 \text{ lb.})]/(1/2)(180000/4 \text{ psi}) \quad = \quad .273 \text{ in}^2 \text{ or } .590'' \text{ diameter.}$$

Pin Diameter (Aluminum 2219-T851)

For aluminum 2219-T851 the cross sectional area of the pin is determined to be:

$$[(1/2)(12300 \text{ lb.})]/(1/2)(63000/4 \text{ psi}) \quad = \quad .781 \text{ in}^2 \text{ or } .997'' \text{ diameter.}$$

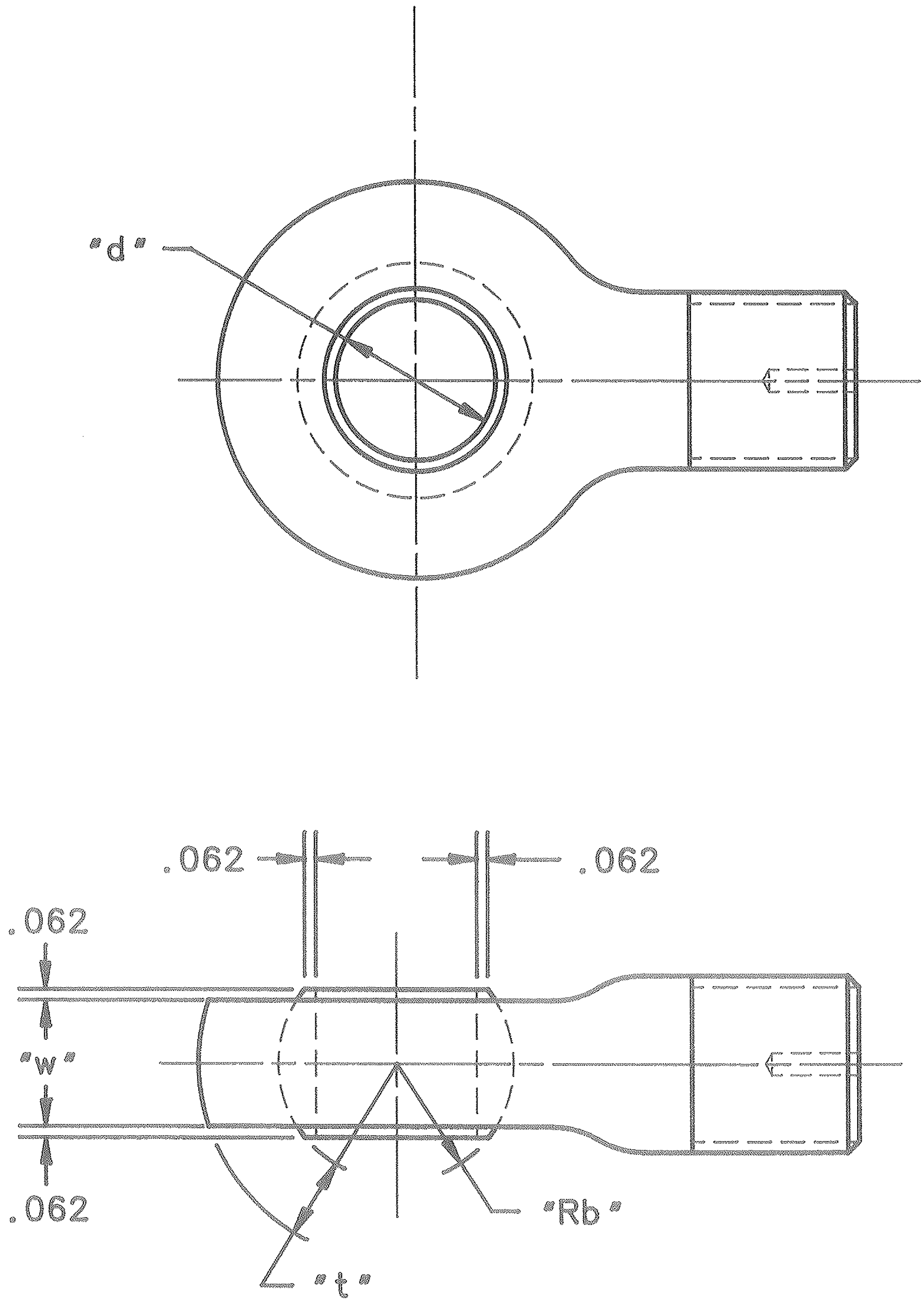


FIGURE 4

Pin Diameter (Aluminum 7075-T6)

For aluminum 7075-T6 the cross sectional area of the pin is determined to be:

$$[(1/2)(12300 \text{ lb.})]/(1/2)(75000/4 \text{ psi}) = .656 \text{ in}^2 \text{ or } .914'' \text{ diameter.}$$

Pin Engagement (See Figure 4)

The length of the pin engagement, w, in the rod end assembly (rod end width) is determined by:

$$\frac{P}{(Fb)(d)}$$

where nomenclature is defined as:

P = Maximum axial force in the composite support rod

Fb = Maximum bearing stress (assumed to be 1/4 ultimate stress)

d = Pin diameter

Pin Engagement (Titanium 6al-4v Pins with Beryllium Copper 172 Balls)

One material choice for the spherical ball is assumed to be beryllium copper 172 which is heat treatable. Also, the yield and tensile strengths of this material increase at low temperatures, while the ductility remains adequate. Hence, the minimum length of pin engagement in the spherical bearing with titanium pins is determined to be:

$$(12300 \text{ lb.})/[(1/4)(175000 \text{ psi})](.695 \text{ in.}) = .405 \text{ in. and,}$$

$$(12300 \text{ lb.})/[(1/4)(130000 \text{ psi})](.695 \text{ in.}) = .545 \text{ in.}$$

for the truss support ball and the truss support pin respectively.

Pin Engagement (Inconel 718 Pins with Beryllium Copper 172 Balls)

The minimum length of pin engagement in the spherical bearing with inconel pins is determined to be:

$$(12300 \text{ lb.})/[(1/4)(175000 \text{ psi})](.590 \text{ in.}) = .477 \text{ in. and,}$$

$$(12300 \text{ lb.})/[(1/4)(180000 \text{ psi})](.590 \text{ in.}) = .463 \text{ in.}$$

for the truss support ball and the truss support pin respectively.

Pin Engagement (Aluminum 2219-T851 Pins with Beryllium Copper 172 Balls)

The minimum length of pin engagement in the spherical bearing with aluminum pins is determined to be:

(12300 lb.)/[(1/4)(175000 psi)](.997 in.) = .282 in. and,

(12300 lb.)/[(1/4)(63000 psi)](.997 in.) = .783 in.

for the truss support ball and the truss support pin respectively.

Pin Engagement (Aluminum 7075-T6 Pins with Beryllium Copper 172 Balls)

The minimum length of pin engagement in the spherical bearing with aluminum pins is determined to be:

(12300 lb.)/[(1/4)(175000 psi)](.914 in.) = .308 in. and,

(12300 lb.)/[(1/4)(75000 psi)](.914 in.) = .718 in.

for the truss support ball and the truss support pin respectively.

Pin Engagement (Titanium 6al-4v Pins with Aluminum 2219-T851 Balls)

If the material of the spherical ball is assumed to be Aluminum 2219-T851, then the minimum length of pin engagement is determined to be:

(12300 lb.)/[(1/4)(63000 psi)](.695 in.) = 1.124 in.

for the truss support ball.

Pin Engagement (Titanium 6al-4v Pins with Aluminum 7075-T6 Balls)

If the material of the spherical ball is assumed to be Aluminum 2219-T851, then the minimum length of pin engagement is determined to be:

(12300 lb.)/[(1/4)(75000 psi)](.695 in.) = .944 in.

for the truss support ball.

Pin Engagement (Inconel 718 Pins with Aluminum 2219-T78 Balls)

The minimum length of pin engagement for an inconel pin with an aluminum ball is determined to be:

(12300 lb.)/[(1/4)(63000 psi)](.590 in.) = 1.324 in.

for the truss support ball.

Pin Engagement (Aluminum 2219-T78 Pins with Aluminum 2219-T78 Balls)

The minimum length of pin engagement for an aluminum pin with an aluminum ball is determined to be:

$$(12300\ \text{lb.})/[(1/4)(63000\ \text{psi})](.997\ \text{in.}) \quad = \quad .783\ \text{in.}$$

for the truss support ball.

Rod End Size (See Figure 4)

The radial thickness, t, of the rod ends is determined by:

$$\frac{P/2}{(Fa)(w)}$$

where nomenclature is defined as:

P = Maximum axial force in composite support rod

Fa = Maximum allowable stress in rod end

w = Width of rod end

Titanium 6al-4v Rod Ends With Titanium 6al-4v Pins and Beryllium Copper 172 Balls

The radial thickness of the rod end for this configuration is determined to be:

$$(1/2)(12300\ \text{lb.})/[(1/4)(130000\ \text{psi})](.545\ \text{in.}) \quad = \quad .347\ \text{in.}$$

Titanium 6al-4v Rod Ends With Inconel 718 Pins and Beryllium Copper 172 Balls

The radial thickness of the rod end for this configuration is determined to be:

$$(1/2)(12300\ \text{lb.})/[(1/4)(130000\ \text{psi})](.477\ \text{in.}) \quad = \quad .397\ \text{in.}$$

Titanium 6al-4v Rod Ends With Aluminum 2219-T78 Pins and Beryllium 172 Copper Balls

The radial thickness of the rod end for this configuration is determined to be:

$$(1/2)(12300\ \text{lb.})/[(1/4)(130000\ \text{psi})](.783\ \text{in.}) \quad = \quad .242\ \text{in.}$$

Inconel 718 Rod Ends With Titanium 6al-4v Pins and Beryllium Copper 172 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(180000 psi)](.545 in.) = .251 in.

Inconel 718 Rod Ends With Inconel 718 Pins and Beryllium Copper 172 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(180000 psi)](.477 in.) = .287 in.

Inconel 718 Rod Ends With Aluminum 2219-T78 Pins and Beryllium Copper 172 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(180000 psi)](.783 in.) = .175 in.

Aluminum 2219-T851 Rod Ends With Titanium 6al-4v Pins and Beryllium Copper 172 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(63000 psi)](.545 in.) = .716 in.

Aluminum 2219-T851 Rod Ends With Inconel 718 Pins and Beryllium Copper 172 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(63000 psi)](.477 in.) = .819 in.

Aluminum 2219-T851 Rod Ends With Aluminum 2219-T851 Pins and Beryllium Copper 172 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(63000 psi)](.783 in.) = .499 in.

Titanium 6al-4v Rod Ends With Titanium 6al-4v Pins and Aluminum 2219-T851 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(130000 psi)](1.124 in.) = .168 in.

Titanium 6al-4v Rod Ends With Titanium 6al-4v Pins and Aluminum 7075-T6 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(130000 psi)](.944 in.) = .200 in.

Titanium 6al-4v Rod Ends With Inconel 718 Pins and Aluminum 2219-T851 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(130000 psi)](1.324 in.) = .143 in.

Titanium 6al-4v Rod Ends With Aluminum 2219-T851 Pins and Aluminum 2219-T851 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(130000 psi)](.783 in.) = .242 in.

Titanium 6al-4v Rod Ends With Aluminum 7075-T6 Pins and Aluminum 7075-T6 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(130000 psi)](.718 in.) = .264 in.

Inconel 718 Rod Ends With Titanium 6al-4v Pins and Aluminum 2219-T851 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(180000 psi)](1.124 in.) = .122 in.

Inconel 718 Rod Ends With Inconel 718 Pins and Aluminum 2219-T851 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(180000 psi)](1.324 in.) = .103 in.

Inconel 718 Rod Ends With Aluminum 2219-T851 Pins and Aluminum 2219-T851 Balls

The radial thickness of the rod end for this configuration is determined to be:

(1/2)(12300 lb.)/[(1/4)(180000 psi)](.783 in.) = .175 in.

Aluminum 2219-T851 Rod Ends With Titanium 6al-4v Pins and Aluminum 2219-T851 Balls

The radial thickness of the rod end for this configuration is determined to be:

$$(1/2)(12300\text{ lb.})/[(1/4)(63000\text{ psi})](1.124\text{ in.}) \quad = \quad .347\text{ in.}$$

Aluminum 2219-T851 Rod Ends With Inconel 718 Pins and Aluminum 2219-T851 Balls

The radial thickness of the rod end for this configuration is determined to be:

$$(1/2)(12300\text{ lb.})/[(1/4)(63000\text{ psi})](1.324\text{ in.}) \quad = \quad .295\text{ in.}$$

Aluminum 2219-T851 Rod Ends With Aluminum 2219-T851 Pins and Aluminum 2219-T851 Balls

The radial thickness of the rod end for this configuration is determined to be:

$$(1/2)(12300\text{ lb.})/[(1/4)(63000\text{ psi})](.783\text{ in.}) \quad = \quad .499\text{ in.}$$

Aluminum 7075-T6 Rod Ends With Titanium 6al-4v Pins and Aluminum 7075-T6 Balls

The radial thickness of the rod end for this configuration is determined to be:

$$(1/2)(12300\text{ lb.})/[(1/4)(75000\text{ psi})](.944\text{ in.}) \quad = \quad .347\text{ in.}$$

Aluminum 7075-T6 Rod Ends With Aluminum 7075-T6 Pins and Aluminum 7075-T6 Balls

The radial thickness of the rod end for this configuration is determined to be:

$$(1/2)(12300\text{ lb.})(1/2)/[(1/4)(75000\text{ psi})](.718\text{ in.}) \quad = \quad .457\text{ in.}$$

Diameter of Spherical Ball (See Figure 4)

If one assumes a minimum radial bearing end thickness of .062 inches and that the bearing protrudes .062 inches from both sides of the rod end as a baseline design, then the ball radius, Rb, is determined by:

$$\sqrt{[(d/2)+(.062\text{ in.})]^2+[(w/2)+(.062\text{ in.})]^2}$$

where nomenclature is defined as:

d = Diameter of the pin

w = Width of the rod end

Diameter of Beryllium Copper 172 Ball (Titanium 6al-4v Pins)

The ball radius for this configuration is determined to be:

$$\sqrt{[(1/2)(.695\text{ in.})+(.062\text{ in.})]^2+[(1/2)(.545\text{ in.})+(.062\text{ in.})]^2} = .529\text{ in.}$$

or 1.058" in diameter.

Diameter of Beryllium Copper 172 Ball (Inconel 718 Pins)

The ball radius for this configuration is determined to be:

$$\sqrt{[(1/2)(.590\text{ in.})+(.062\text{ in.})]^2+[(1/2)(.477\text{ in.})+(.062\text{ in.})]^2} = .467\text{ in.}$$

or .933" in diameter.

Diameter of Beryllium Copper 172 Ball (Aluminum 2219-T851 Pins)

The ball radius for this configuration is determined to be:

$$\sqrt{[(1/2)(.997\text{ in.})+(.062\text{ in.})]^2+[(1/2)(.783\text{ in.})+(.062\text{ in.})]^2} = .721\text{ in.}$$

or 1.442" in diameter.

Diameter of Aluminum 2219-T851 Ball (Titanium 6al-4v Pins)

The ball radius for this configuration is determined to be:

$$\sqrt{[(1/2)(.695\text{ in.})+(.062\text{ in.})]^2+[(1/2)(1.124\text{ in.})+(.062\text{ in.})]^2} = .746\text{ in.}$$

or 1.493" in diameter.

Diameter of Aluminum 2219-T851 Ball (Inconel 718 Pins)

The ball radius for this configuration is determined to be:

$$\sqrt{[(1/2)(.590\text{ in.})+(.062\text{ in.})]^2+[(1/2)(1.324\text{ in.})+(.062\text{ in.})]^2} = .807\text{ in.}$$

or 1.614" in diameter.

Diameter of Aluminum 2219-T851 Ball (Aluminum 2219-T851 Pins)

The ball radius for this configuration is determined to be:

$$\sqrt{[(1/2)(.997\text{ in.})+(.062\text{ in.})]^2+[(1/2)(.783\text{ in.})+(.062\text{ in.})]^2} = .721\text{ in.}$$

or 1.442" in diameter.

Diameter of Aluminum 7075-T6 Ball (Titanium 6al-4v Pins)

The ball radius for this configuration is determined to be:

$$\sqrt{[(1/2)(.695\text{ in.})+(.062\text{ in.})]^2+[(1/2)(.944\text{ in.})+(.062\text{ in.})]^2} = .673\text{ in.}$$

or 1.346" in diameter.

Diameter of Aluminum 7075-T6 Ball (Aluminum 7075-T6 Pins)

The ball radius for this configuration is determined to be:

$$\sqrt{[(1/2)(.914\text{ in.})+(.062\text{ in.})]^2+[(1/2)(.718\text{ in.})+(.062\text{ in.})]^2} = .668\text{ in.}$$

or 1.337" in diameter.

Support System Spring Constant

The magnetic spring constant is assumed to be 132,000 lb/in in the radial direction and 145,300 lb/in in the axial direction. The spring constant for the support system is determined to be:

(decentering load)/(maximum coil connection point displacement)

Therefore, the spring constant for the truss due to axial loading is:

(145,300 lb.)/(.018 in.) = 8.07e6 lb/in

Similarly, the spring constant for the truss due to radial loading is:

(132,000 lb.)/(.022 in.) = 6.00e6 lb/in

In both cases the spring constant of the support system is much greater than the magnetic spring constant of the coil in the respective directions. Therefore, the support system is considered to be stable with a one inch magnetic offset.

Slide

The total movement in the slide after cooldown is .018 inches. This is due to the axial decentering force increasing during excitation. The charging time of the coil has been estimated to be a minimum of 20.3 minutes at 220 watts (DN-119). Therefore, the rate of displacement in the slide is approximately .001 inch/minute.

Reaction Forces at End Connection

The maximum reaction forces for any support rod connection point are listed below. All forces should be considered bidirectional.

S	Load Component	Max. RFradial	Max. RFtheta	Max. RFz
L	Axial Load	0	0	0
I	Radial load	300	7850	1600
D				
E	Total	300*	7850	1600*
C				
H	Axial Load	1500	0	9100
I	Radial Load	350	8000	2000
M				
N	Total	1850*	8000	11100
E				
Y	* Denotes forces to be absorbed by the vacuum chamber.			

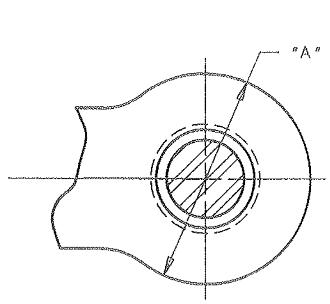
Conclusion

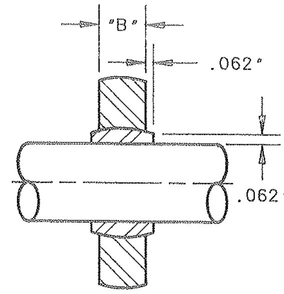
The comparative sizes of the metallic rod end assemblies for various materials are listed in Table 1. Item 16 is 1.864" O.D. x .718" wide with a maximum radiation length of .737. The use of titanium 6al-4v for the ball housing makes it an excellent choice for the warm end of the support. Although the yield and ultimate strengths of Titanium 6al-4v increase significantly at cryogenic temperatures, toughness decreases making it a poor choice for the cold end. However, Aluminum 2219-T851 remains relatively ductile at liquid helium temperatures. Therefore,item 1 is the apparent choice for the cold end assembly. It is 2.440" O.D. x .783" wide with a maximum radiation length of .780. However, this is the size of the rod end based on material properties at 300 K. Figure 5 (MH) and Figure 6 (MH) are graphs of the minimum ultimate strength and minimum yield strength of aluminum 2219-T851 as a function of temperature. It can be seen that both the ultimate strength and the yield strength increase significantly at cryogenic temperatures. Furthermore, the magnetic decentering load is only present when the coil is energized at 4.2 K. Therefore, the use of material properties at 77 K for the cold rod end is realistic yet conservative. The use of the warm properties provides a rod end that is 2.242" O.D. x .715" wide with a maximum radiation length of .716.

Figure 7 is a conceptual drawing of a CFRP composite support rod assembly complete with the selected rod ends. The spherical balls are coated with Microseal 100-1 graphite impinged coating to increase bearing efficiency and eliminate the risk of galvonic corrosion.

This prelimiminary investigation indicates that a trussed composite rod support system is viable in terms of mechanical strength, physical thickness, and radiation length. The angled geometry of the rods minimizes particle interaction at the connection points and the no preload, self adjusting concept after coil cooldown is a great advantage over conventional isolated function support systems.

a2 = Aluminum 2219-T851
a7 = Aluminum 7075-T6
i = Inconel 718
b = Beryllium copper 172
t = Titanium 6al-4v





ITEM	Material ROD END	Material BALL	Material PIN	"A" Thickness (inches)	"B" Width (inches)	"A" Thickness (radiation lengths)
1.	a2	a2	a2	2.440	.783	.780
2.	a2	a2	i	2.204	1.324	1.429
3.	a2	a2	t	2.186	1.124	1.101
4.	a2	b	a2	2.440	.783	1.416
5.	a2	b	i	2.572	.477	2.039
6.	a2	b	t	2.490	.545	1.684
7.	a7	a7	a7	2.250	.718	.635
8.	a7	a7	t	2.040	.944	.971
9.	i	a2	a2	1.792	.783	1.003
10.	i	a2	i	1.820	1.324	1.561
11.	i	a2	t	1.736	1.124	1.224
12.	i	b	a2	1.792	.783	1.638
13.	i	b	i	1.508	.477	1.203
14.	i	b	t	1.560	.545	2.003
15.	t	a2	a2	1.926	.783	.790
16.	t	a7	a7	1.864	.718	.737
17.	t	a7	t	1.746	.944	1.050
18.	t	a2	i	1.220	1.324	1.711
19.	t	a2	t	1.828	1.124	1.076
20.	t	b	a2	1.926	.783	1.426
21.	t	b	i	1.728	.477	2.058
22.	t	b	t	1.752	.545	1.700

Table 1
Rod End Material Size Data

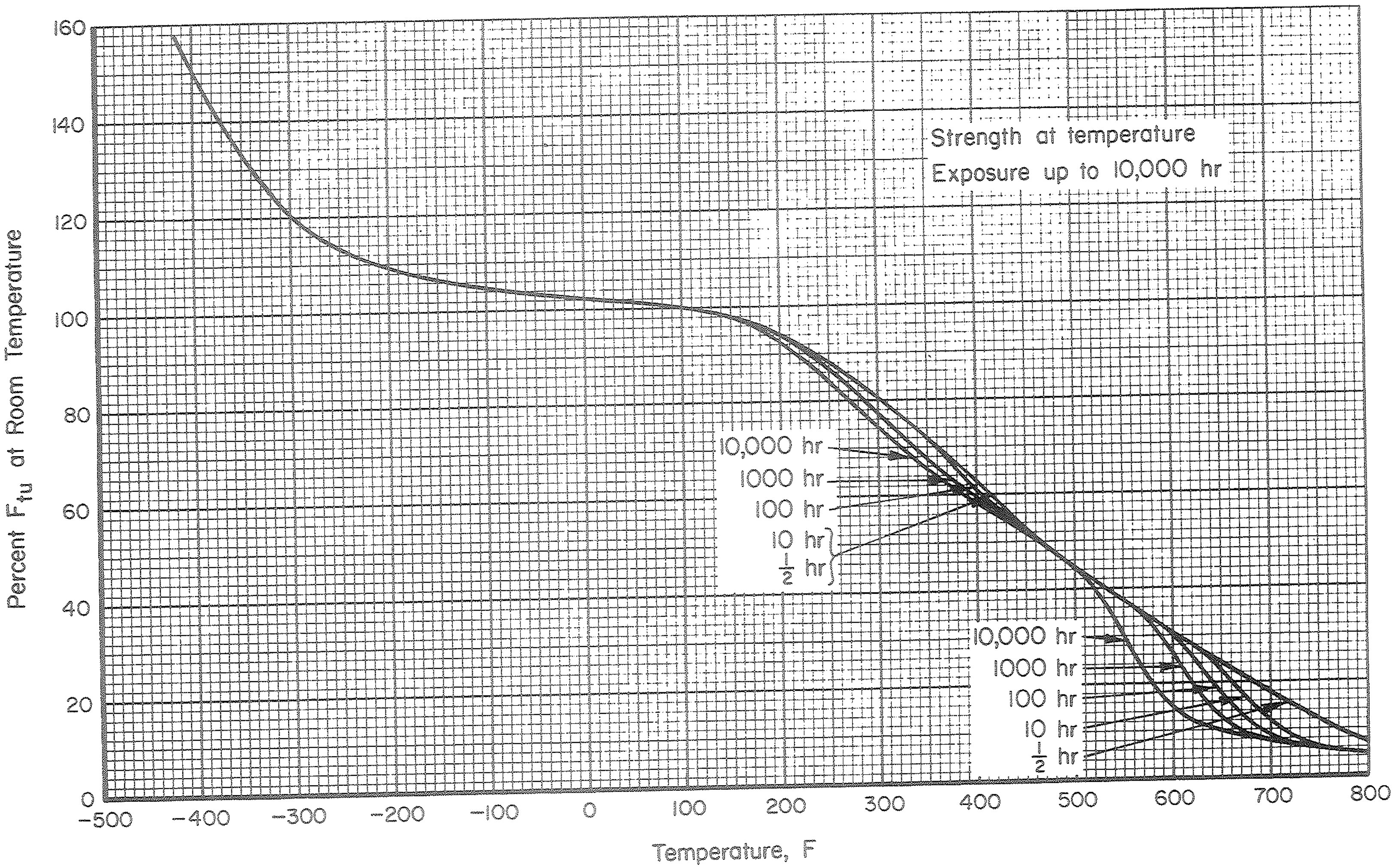


FIGURE 5 *Effect of temperature on the tensile ultimate strength (F_{tu}) of 2219-T62 aluminum alloy bare and clad sheet and plate 0.040–1.000 in. thick.*

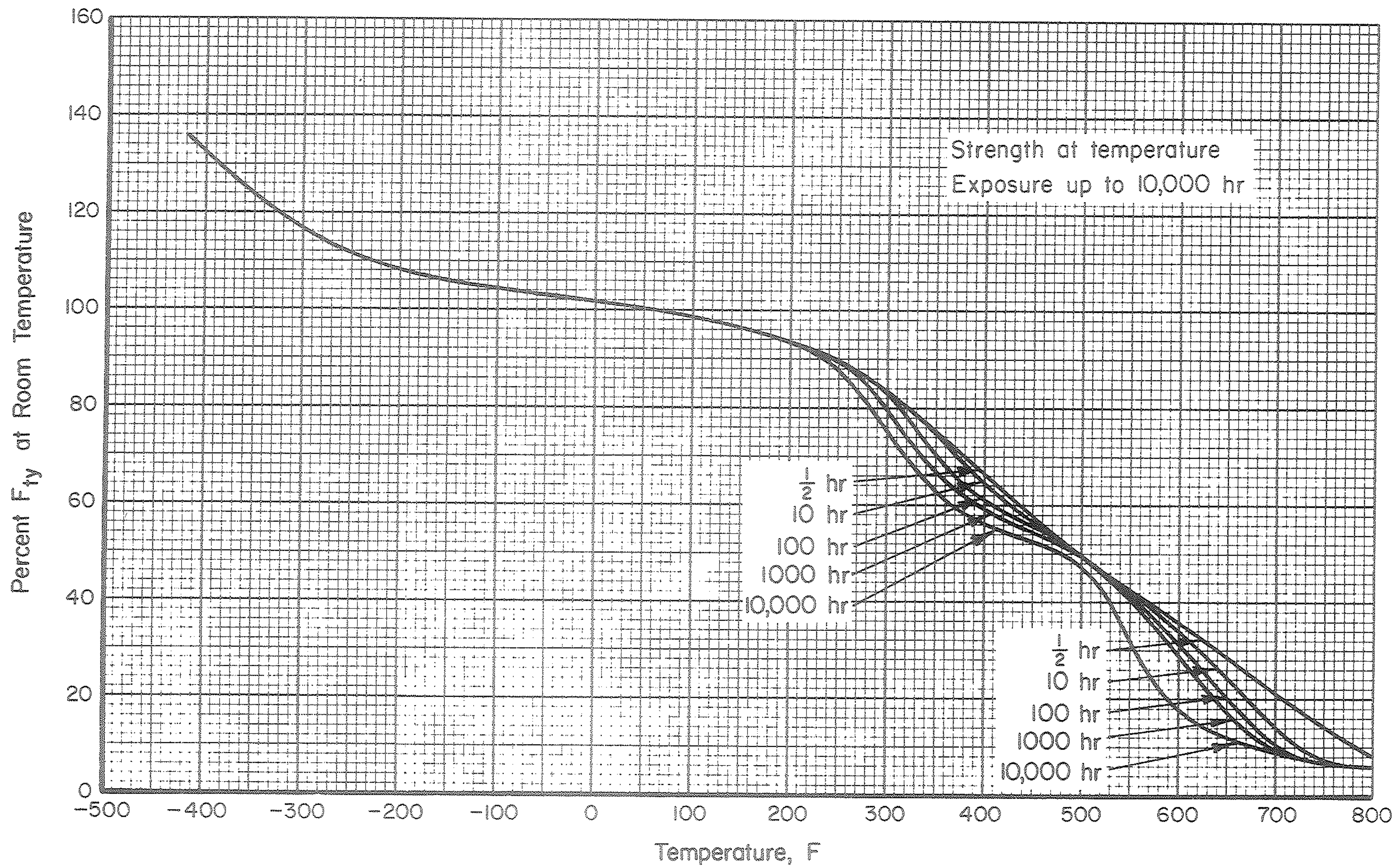


FIGURE 6 *Effect of temperature on the tensile yield strength (F_{ty}) of 2219-T62 aluminum alloy bare and clad sheet and plate 0.040–1.000 in. thick.*

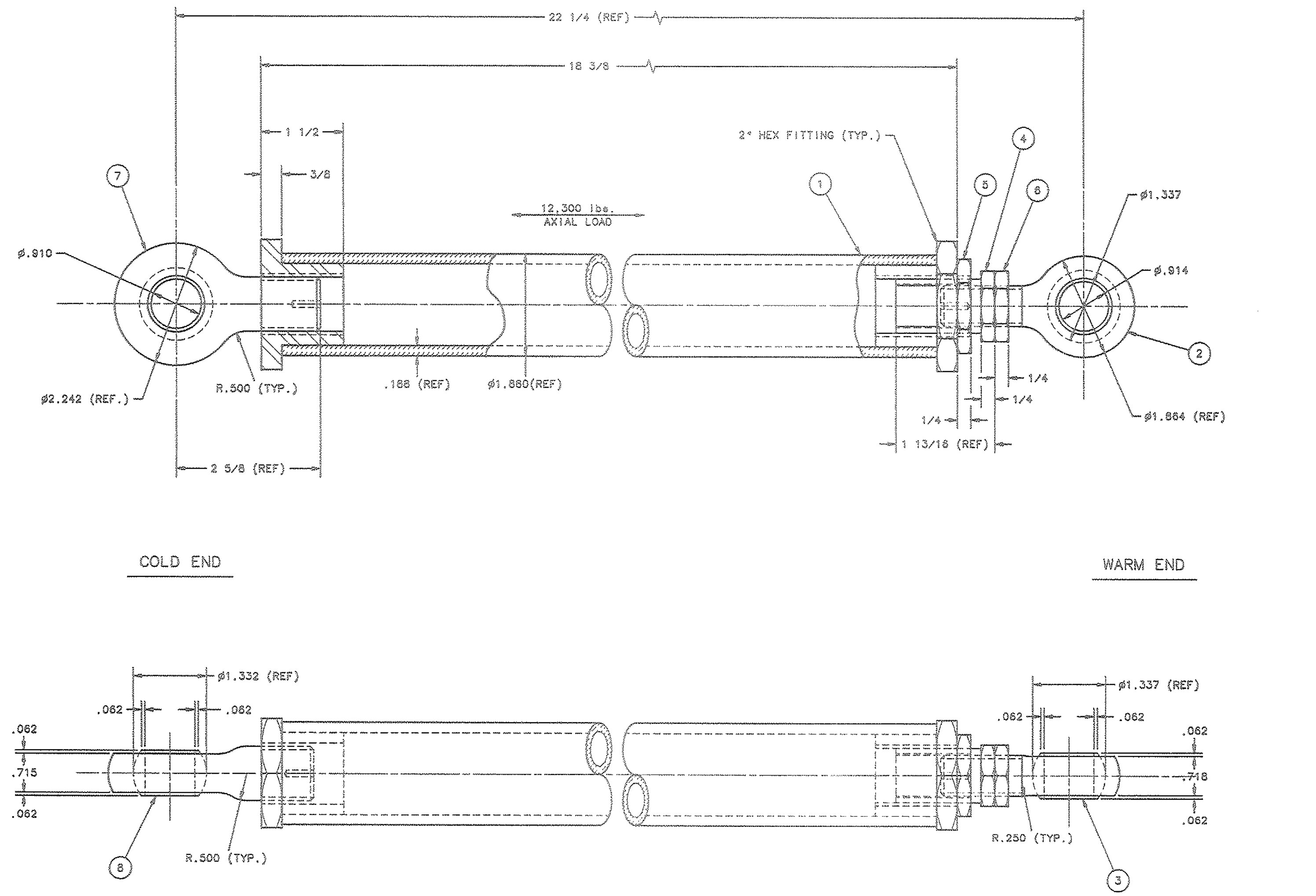


FIGURE 7

REV.	DESCRIPTION	DRAWN / APPROVED	DATE / DATE

PARTS LIST

ITEM NO.	PART NO.	DESCRIPTION OR SIZE	QTY. REQ.
8	COMMER'L	SPHERICAL BEARING (WARM END); ALUMINUM 7075-T6 CONSTR., 1.332 O.D. x 0.839" THK., WITH IMPINGED GRAPHITE COATING MICROSEAL 100-1 OR EQUAL	1
7	COMMER'L	ROD END (COLD END); ALUMINUM 2219-T851 CONSTR., 2.242 O.D. x 2 3/8" LG. WITH 1"-12UNF-RH x 1 1/16" LG. THREADS	1
6	COMMER'L	LOCK NUT, (WARM END); ALUMINUM 7075-T6 CONSTR., 3/4"-16UNF-LH x 1/4" THK.	1
5	COMMER'L	LOCK NUT, (WARM END); ALUMINUM 7075-T6 CONSTR., 1"-12UNF-RH x 1/4" THK.	1
4	COMMER'L	ROD INSERT (WARM END); TITANIUM 6AL-4V (ELI) CONSTR., 1"-12UNF-RH MALE THREADS x 3/4"-16UNF-LH FEMALE THREADS	1
3	COMMER'L	SPHERICAL BEARING (WARM END); ALUMINUM 7075-T6 CONSTR., 1.337 O.D. x 0.843" THK., WITH IMPINGED GRAPHITE COATING MICROSEAL 100-1 OR EQUAL	1
2	COMMER'L	ROD END (WARM END); TITANIUM 6AL-4V (ELI) CONSTR, 1.864 O.D. x 2 3/8" LG. W/3/4"-16UNF-LH x 1 1/16" LG. THRDS	1
1	COMMER'L	SUPPORT ROD; 1.88 O.D. x .188 WALL THKNSS. CFRP FILAMENT WOUND COMPOSITE ROD WITH INTEGRALLY WOUND END FITTINGS TITANIUM 6AL-4V (ELI) CONSTR. WITH 1"-12UNF-RH FEMALE THRU THREADS	1

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	J. KREBS	8/91
FRACTIONS	DECIMALS	ANGLES	DRAWN	D. FRIEND	8/16/91
±1/32	±.005	± 1°	CHECKED	N. J. Krebs	8.15.91
			APPROVED		
			USED ON		

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRWG.
3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD's.

125 √ MAX. ALL MACHINED SURFACES

MATERIAL: AS LISTED ABOVE — D

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

SOLENOIDAL DETECTOR COLLABORATION
SUPERCONDUCTING SOLENOID
CONCEPTUAL SUPPORT ROD ASSEMBLY

SCALE	DRAWING NUMBER	SHEET NO.	REV.
FULL		1	

References

MH MIL-HDBK-5E, June 1,1987, "Metallic Materials and Elements for Aerospace Vehicle Applications", Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19111-5094.

DN-119 SDC Design Note #119, November 7,1990, "Transient Heat Load to Outer Support Cylinder from Eddy Currents", R.W. Fast, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510

DN-126 SDC Design Note #126, December 20, 1990, "CGA Calculations for Homogeneous Outer Vacuum Shells; Thickness for Typical Materials", R. W. Fast, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510.

DN-149 SDC Design Note #149, July 26,1991, "Radial and Axial Decentering Forces for Several SDC Solenoid/Calorimeter Configurations", B. Wands, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510.