DØ SOLENOID UPGRADE PROJECT

Heat Loads in the D0 Solenoid Cryostat

D-ZERO ENGINEERING NOTE # 3823.111-EN-361

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INTRODUCTION

The heat loads in the cryostat are in the form of radiation, conduction, and internal heat generation due to eddy currents caused by the changing field. Most of the heat is removed by liquid nitrogen cooled shields and intercepts. Eddy current heating is prevented in the shield by splitting the shield longitudinally and maintaining the gap with a G-10 plate. Contraction of the shield is allowed by slotting the attachment holes for the shield standoff supports.

INSULATION

The cryostat is vacuum insulated and is pumped down through the chimney. To obtain low emissivity surfaces, all surfaces are covered with aluminum tape (3M #425). To reduce the thermal radiation from the vacuum jacket, multi-layer insulation (MLI) 18 mm (0.71") thick at a density of 10 layers/cm (25 layers/in) is placed between the shield and vacuum jacket. Studies[1,2] show that this will reduce the heat flux to about 1 W/m^2. No MLI is used between the radiation shield and the coil. This is based upon a study that showed that 3M #425 aluminum tape alone will provide a lower heat load than using MLI[3]. This is only true with a high vacuum. Since it is possible to maintain a good vacuum for small leaks with a turbomolecular pump, one will be installed in case a small leak develops.

SUPPORT INTERCEPTS

Liquid nitrogen cooled intercepts are being used on all supports. On the radial supports, additional heat must be intercepted at the coil end of the support in order to maintain a coil temperature below 4.9 K during steady current operation.

DISCUSSION

Table 1 summarizes the heat loads in the cryostat. The appendices show the heat load calculations. For these calculations, certain conservative assumptions were made. For the heat loads from the vacuum jacket to the nitrogen shields and intercepts, the temperatures were taken to be 300 and 78 K. For the heat loads from the nitrogen shields and intercepts to the coil, the temperatures were 90 and 4.2 K. Some refinements were necessary when dealing with the radial supports since heat intercept straps are being used. In this case, the temperatures used are from an ANSYS analysis of the coil temperature near a radial support block. The strap calculation indicates that a 1 mm diameter 12 cm long strap of high purity aluminum (RRR 1000) would reduce the heat load to the coil to 0.03 W per support. Because of the small diameter required, a larger strap will be used thus reducing the heat load to less than 0.03 W per radial support.

Contingency has been added to some of the heat loads calculated. Experience shows that there is uncertainty in a radiation heat load calculation, therefore, the radiation

heat load to the helium surface listed in Table 1 includes a factor of 10 increase from the calculated value. For the radiation heat load to the shield from the vacuum jacket, a factor of 5 was used.

During charging and discharging of the coil, additional heat will be generated in the support cylinder. For a 12 A/s charging rate, 20 W of additional heat will be generated. The expected normal charging rate is not expected to be much larger than 6.7 A/s.

Table 1. Summary of the cryostat thermal heat loads.

	300 to ~85 K W	85 to 4.7 K W
Cryostat		
Radiation	130	9.3
Conduction		
Thirty two Shield standoffs	16	---
Six axial supports	6.6	0.5
Twelve radial supports	16.7	2.7
Eddy current in support cylinder (charging)	---	20

REFERENCES

1. T. Ohmori et al, Thermal performance of candidate SSC magnet thermal insulation systems, Adv. in Cryo. Eng., 33:323 (1988).
2. Q.S. Shu, R.W. Fast, and H.L. Hart, An experimental study of heat transfer in multilayer insulation systems from room temperature to 77 K, Adv. in Cryo. Eng., 31:455 (1986).
3. E.M.W. Leung, R.W. Fast, H.L. Hart, and J.R. Heim, Techniques for reducing radiation heat transfer between 77 and 4.2 K, Adv. in Cryo. Eng., 25:489 (1980).

Appendix

Heat Load Calculations

The following pages are the calculations for the heat load calculations.

Calculation	Pages
Radiation Heat Load to Coil	A1 - A2
Radiation Heat Load to Shield	A3 - A4
Conduction Heat Load to Coil	A5 - A15
Conduction Heat Load to Shield	A16 - A17
Eddy Current Heating in Support Cylinder	A18 - A19

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL - CATEGORY	PAGE
	RD/MSD	D0	Solenoid	A1

SUBJECT: Radiation Heat Load (Shield to Coil)

NAME: B. Squires

DATE: 15-Oct-92

REVISION DATE:

Radiation Heat Load

Support Cylinder
OD = 133 cm

Outer Cryostat
ID = 142.6 cm ΔD = 7.6 cm (~4¾")

Coil
ID = 121.6 cm

Inner Cryostat
OD = 114.4 cm ΔD = 7.2 cm (~2¾")

assume 2 cm Between outer cryostat & inner surface of radiation shield

∴ r_{sc} = 66.5 cm r_{rs} = 69.3 Δr = 2.8 cm

Using Eq's from Incropera & DeWitt "Fundamentals of Heat Transfer", 1981 Example 13.6 p. 657 put into TK solver Plus (see page A2)

Outer

St	Input	Name	Output	Unit	Comment
	'no	shield		---	Is there a Floating radiation shield?
		sigma	5.67E-8	W/m2K4	Stefan-Boltzmann Constant
	.6598	r1		m	Radius of inner cylinder
	.69865	r2		m	Radius of outer cylinder
		r3		m	Radius of floating radiation shield
	2.5970316	L		m	Length of Cylinders
	4.2	T1		K	Temperature of inner cylinder
	90	T2		K	Temperature of outer cylinder
	.011	e1		---	Emissivity of inner cylinder
	.03	e2		---	Emissivity of outer cylinder
		e3		---	Emissity of floating radiation shield
L		q12	-.329794	W	Heat Load from inner to outer cylinder
L		Q1	-.0289285	W/m2	Heat Flux from surface 1

Inner

St	Input	Name	Output	Unit	Comment
	'no	shield		---	Is there a Floating radiation shield?
		sigma	5.67E-8	W/m2K4	Stefan-Boltzmann Constant
	.5702	r1		m	Radius of inner cylinder
	.617	r2		m	Radius of outer cylinder
		r3		m	Radius of floating radiation shield
	2.5970316	L		m	Length of Cylinders
	90	T1		K	Temperature of inner cylinder
	4.2	T2		K	Temperature of outer cylinder
	.03	e1		---	Emissivity of inner cylinder
	.011	e2		---	Emissivity of outer cylinder
		e3		---	Emissity of floating radiation shield
L		q12	.2973018	W	Heat Load from inner to outer cylinder
L		Q1	.02952944	W/m2	Heat Flux from surface 1

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL - CATEGORY	PAGE
	RD/MSD	Do	Solenoid	A2

SUBJECT	NAME	DATE	REVISION DATE
Radiation	B. Squires	15-Oct-92	

- CDF design note increased Heat flux by factor of 2
- CDF design note underestimated Heat Load (Radiation) by a factor of 4

∴ I will use a factor of 10

also assume each end is half the heat load of the inner shield

outer = 0.33
Inner = 0.30
2 ends = 0.30 → 0.034 if using Q of inner shield and end areas (6.4w)
0.93 watts

∴ assume total Radiation Heat Load is 9.3 watts

Equations used ↓

Main
S Rule

```
"Equations based on Example 13.6 p.657 in
"'Fundamentals of Heat Transfer' by Incropera and Dewitt (1981)

sigma=5.67e-8  "Stefan-Boltzmann Constant in W/m2K4
* if shield='yes then call cylshield(r1,r2,r3,L,T1,T2,e1,e2,e3;q12)
if shield ='no then call cylinders(r1,r2,L,T1,T2,e1,e2;q12)
Q1=q12/(pi()*2*r2*L)
```

Routine: Cylinders

```
Comment:                Two concentric cylinders
Parameter Variables:    sigma
Argument Variables:     r1,r2,L,T1,T2,e1,e2
Result Variables:       q12
S Rule
  "Checked out okay on 15-Oct-92
  "e# = emisivity of surface #
  "r# = radius of surface #  (m)
  "A1 = area of surface #    (m2)
  "T# = temperature of surface #  (K)
  "q12 = heat transfer from surface 1 to 2 (if negative then 2 to 1) (Watt)
  "L = length of cylinders    (m)
  A1=2*pi()*r1*L
  q12=sigma*A1*(T1^4-T2^4)/(1/e1+(1-e2)/e2*(r1/r2))
```

DØ Solenoid 300K to 78K heat Load Calculation AS

St	Input	Name	Output	Unit	Comment
					MAJOR AREAS OF HEAT LOAD
	2.595	L		m	Length of Cylinders
	.71706	rvjo		m	Inside radius of outer vac. jacket
	.69706	ro		m	Outside radius of shield
	.59335	ri		m	Inside radius of inner shield
	2	ce		---	Contingency factor on Aend
		Aend	1.6817375	m2	total area for ends
		Aout	11.691567	m2	area of outer vacuum jacket
		Ain	9.6744922	m2	area of inner shield
	.75	Q		W/m2	Heat flux w/ MLI and Tape
		qend	1.2613032	W	Heat load on ends
		qout	8.7686753	W	Heat load on outer shield
		qin	7.2558691	W	Heat load on inner shield
					MINOR AREAS OF HEAT LOAD (HOLES)
	150	Qh		W/m2	heat flux for holes
	.25	rrad		in	radius of radial support
	.3125	rax		in	radius of axial support
	.125	rat		in	radius of shield sup't
	.25	trad		in	gap around radial support
	.25	tax		in	gap around axial support
	.25	tat		in	gap around shield support
	12	nrad		---	number of radial supports
	6	nax		---	number of axial supports
	32	nat		---	number of shield support holes
		Arad	.00456048	m	Hole area for radial support
		Aax	.00266028	m2	Hole area for axial support
		Aat	.00810752	m2	Hole area for shield supports
		qrad	.68407173	W	heat load due to radial sup't holes
		qax	.39904184	W	heat load due to axial sup't holes
		qat	1.2161275	W	heat load due to shield sup't holes
		qh	2.2992411	W	total heat load due to holes
					RESULTS OF HEAT LOAD CALCULATION
		q	19.585089	W	Total heat load
		c	6.6377029	---	Contingency factor on q
	130	qused		W	Heat load used

units used in equation are meters

$1 \frac{W}{m^2}$ for 20 Layers @ $2.8 \frac{\text{layers}}{mm}$ ohmori et.al

$0.75 \frac{W}{m^2}$ for 18 Layers @ $1.1 \pm 0.2 \frac{\text{layers}}{mm}$ shu et.al. (Vol. 31)

max. $150 \frac{W}{m^2}$ for slots and holes in MLI shu et.al. (Vol. 33)

Note: if setting $Q = 1 \frac{W}{m^2}$; $q = 25.35\ W$ & $c = 5.13$

Rule Equations for 300K to 18K Heat Load Calc.

A4

```
"Equations for MLI given heat flux (Q) through MLI
Aend=pi()*(ro^2-ri^2)*2*ce "2 ends
Aout=pi()*2*rvjo*L
Ain=pi()*2*ri*L
qend=Q*Aend
qout=Q*Aout
qin=Q*Ain
q=qend+qout+qin+qh
qused=q*c

"Holes in MLI
Arad=pi()*((rrad+trad)^2-rrad^2)*nrad
Aax=pi()*((rax+tax)^2-rax^2)*nax
Aat=pi()*((rat+tat)^2-rat^2)*nat
qrad=Qh*Arad
qax=Qh*Aax
qat=Qh*Aat
qh=qrad+qax+qat
```

St	Input	Name	Output	Unit	Comment
					D0 Solenoid Axial Supports
					~~ Total Loads ~~~~~~~~~~~~~
	6	N		---	Number of Supports
	1.46	m		tonne	Mass of Cold Mass
		Tt	10.262931	tonne	Total Load on supports
		Gs	7.0294049	---	G loading [# G's]
	300	Tw		K	Warm end Temperature
	90	Tic		K	Intercept Temperature for the cold end
	78	Tiw		K	Intercept Temperature for the warm end
	4.5	Tc		K	Cold end Temperature
		Qct	.44458499	watt	Total Heat Load on Cold End
		Qwt	6.5887632	watt	Total Heat Load on Warm End
					~~ A Single Support ~~~~~~~~~~
		T	1.7104885	tonne	Applied Tensile Load
		Lc	10.765558	in	Length of the Cold End
		Lw	3.7739123	in	Length of the Warm End
		L	14.53947	in	Total Length of the Support
		Lf	5.0225295	in	Spherical Bearing End Effect
	19.562	Lp		in	Length Between Pivot Points
	.0838	Aw		in2	Cross Sectional Area for the Warm End
		Dw	.32664579	in	Effective Diameter of the Warm End
	45	Saw		ksi	Allowable Stress for the Warm End
		Kcdt	3.7476788	W/cm	Thermal Conductivity Integral/Cold End
		Kwdt	19.470035	W/cm	Thermal Conductivity Integral/Warm End
		Qc	.0740975	watt	Heat Load on the Cold End
		Qw	1.0981272	watt	Heat Load on the Warm End
					~~ Euler's Formula ~~~~~~~~~~~
	31000000	E		psi	Young's Modulus
	1	n		---	End condition
		Ro	.3125	in	Outer Radius of cylinder
		Ri	.26642425	in	Inner radius of cylinder
		I	.00353297	in4	Moment of inertia
		r	.20532787	in	Radius of Gyration
	.625	Do		in	Outer Diameter of cylinder
		Di	.5328485	in	Inner Diameter of cylinder
		Pcr	2824.7157	lbf	Critical Load from Euler's Formula
		Sigma	33.707824	ksi	Critcal Stress (typically > Yield)
		Pd	706.17892	lbf	Buckling Design Load
	4	Safety		---	Safety Factor on Pd
		Gb	1.153019	---	G Loading for Buckling [# g's]
					~~Seismic Loading~~~~~~~~~~~~~~~~
	.1875	Z		---	Seismic Zone Coefficient
	1.5	Is		---	Occupancy Importance Factor
	2	K		---	Horizontal Force Factor
	.14	CS		---	Numerical Coefficient & Soil Factor
		G	.07875	---	Seismic Loading G Factor
	456	Pc		lbf	Loading on support due to cooldown
		W	3674.7647	lbf	Dead Load
		V	289.38772	lbf	Load that support system must handle
		V%6	48.231286	lbf	Load that each support must handle

Main equations for axial support Calculation

S Rule

```
"Using warm area for the design
T=Saw*Aw
Kwdt=dfnipoly(Tiw,Tw,'Kpoly718)
Kcdt=dfnipoly(Tc,Tic,'Kpoly718)
Qc=Aw/Lc*Kcdt*2.54/100
Qw=Aw/Lw*Kwdt*2.54/100
call Solid(;Qc,Qw,Kwdt,Kcdt)

Lp=L+Lf
L=Lc+Lw
Aw=(Dw/2)^2*pi()

Qct=N*Qc
Qwt=N*Qw


"for Euler Collapse equation
Pcr=n*pi()^2*E*I/Lp^2
I=Aw*r^2
r=0.5*sqrt(Ro^2+Ri^2)  "r is the Radius of Gyration for a cylinder
Sigma=Pcr/Aw
Aw=pi()*(Ro^2-Ri^2)
Do=2*Ro "to help in conceptualization
Di=2*Ri "ditto
Pd=Pcr/Safety  "Design Load for Compression Loading


"some mass equations
Tt=T*N
Gs=Tt/m

"Buckling Criteria for Seismic Loadings
"from "Minimum Design Loads for Buildings and Other Structures"
"ASCE Standard ASCE 7-88 (Formerly ANSI A58.1)  approved Dec-88
Gb=6*Pd/(m+Pc)
G=Z*Is*K*CS
W=m+Pc
V%6=V/6
V=G*W
```

Solid Routine for Axial Support Calculation

Comment: This calculates heat loss for areas & lengths
Parameter Variables: Tiw,Tic,Tw,Tc,Aw
Input Variables:
Output Variables: Qc,Qw,Kwdt,Kcdt

Statement

```
Kwdt=dfnipoly(Tiw,Tw,'Kpoly718)
Kcdt=dfnipoly(Tc,Tic,'Kpoly718)

'A[3]=Aw
'A[5]=Aw



L%A=0
j=length('A)
k=member(0,'A)
call blank('L,j+1)


for i=1 to k-1
L%A='L[i]/'A[i]+L%A
next i
A%L=1/L%A
Qc=A%L*Kcdt*2.54/100
L%A=0
for i=k+1 to j
L%A='L[i]/'A[i]+L%A
next i
A%L=1/L%A
Qw=A%L*Kwdt*2.54/100

'L[j+1]=sum('L)
```

Lists for Axial Support Calculation

A8

Title:

Element	A	L	Comment
1	.441786467	.5	'Cold_end
2	.306796158	.625	
3	.0838	10.5	
[illegible]	0	0	
5	.0838	3	'Warm_end
6	.306796158	.75	
7	.110446617	.75	
8		16.125	

St	Input	Name	Output	Unit	Comment
					D0 Solenoid Radial Supports
					~~ Total Loads ~~~~~~~~~~~~~
	12	N		---	Number of Supports
	1.46	m		tonne	Mass of Cold Mass
		Tt	48.093599	tonne	Total Load on supports
		Gs	32.940821	---	G loading [# G's]
	300	Tw		K	Warm end Temperature
	90	Tic		K	Intercept Temperature for the cold end
	78	Tiw		K	Intercept Temperature for the warm end
	4.5	Tc		K	Cold end Temperature
		Qct	2.2684056	watt	Total Heat Load on Cold End
		Qwt	16.675918	watt	Total Heat Load on Warm End
					~~ A Single Support ~~~~~~~~~~
		T	4.0077999	tonne	Applied Tensile Load
		Lc	9.8875	in	Length of the Cold End
		Lw	6.9875	in	Length of the Warm End
		L	16.875	in	Total Length of the Support
		Aw	.19634954	in2	Cross Sectional Area for the Warm End
	.5	Dw		in	Effective Diameter of the Warm End
	45	Saw		ksi	Allowable Stress for the Warm End
		Kcdt	3.7476788	W/cm	Thermal Conductivity Integral/Cold End
		Kwdt	19.470035	W/cm	Thermal Conductivity Integral/Warm End
		Qc	.1890338	watt	Heat Load on the Cold End
		Qw	1.3896598	watt	Heat Load on the Warm End
					~~ Euler's Formula ~~~~~~~~~~~
		E		psi	Young's Modulus
		n		---	End condition
		Ro		in	Outer Radius of cylinder
		Ri		in	Inner radius of cylinder
		I		in4	Moment of inertia
		r		in	Radius of Gyration
		Do		in	Outer Diameter of cylinder
		Di		in	Inner Diameter of cylinder
		Pcr		tonne	Critical Load from Euler's Formula
		Sigma		ksi	Critcal Stress (typically > Yield)

Main equations for Radial Support Calculation


```
S Rule
  "Using warm area for the design
* T=Saw*Aw
* Kwdt=dfnipoly(Tiw,Tw,'Kpoly718)
* Kcdt=dfnipoly(Tc,Tic,'Kpoly718)
* Qc=Aw/Lc*Kcdt*2.54/100
* Qw=Aw/Lw*Kwdt*2.54/100

* call Solid(Aw;Qc,Qw,Kwdt,Kcdt)


* L=Lc+Lw
* Aw=(Dw/2)^2*pi()

* Qct=N*Qc
* Qwt=N*Qw


  "for Euler Collapse equation
* Pcr=n*pi()^2*E*I/L^2
* I=Aw*r^2
* r=0.5*sqrt(Ro^2+Ri^2)  "r is the Radius of Gyration for a cylinder
* Sigma=Pcr/Aw
* Aw=pi()*(Ro^2-Ri^2)
* Do=2*Ro "to help in conceptualization
* Di=2*Ri "ditto


  "some mass equations
* Tt=T*N
* Gs=Tt/m
```

Solid Routine for Radial Support Calculation

Comment: This calculates heat loss for areas & lengths
Parameter Variables: Tiw,Tic,Tw,Tc
Input Variables: A
Output Variables: Qc,Qw,Kwdt,Kcdt

S Statement

```
Kwdt=dfnipoly(Tiw,Tw,'Kpoly718)
Kcdt=dfnipoly(Tc,Tic,'Kpoly718)


L%A=0
j=length('A)
k=member(0,'A)
call blank('L,j+1)

'A[k-1]=A
'A[k+1]='A[k-1]

for i=1 to k-1
L%A='L[i]/'A[i]+L%A
next i
A%L=1/L%A
Qc=A%L*Kcdt*2.54/100
L%A=0
for i=k+1 to j
L%A='L[i]/'A[i]+L%A
next i
A%L=1/L%A
Qw=A%L*Kwdt*2.54/100

'L[j+1]=sum('L)
```

Title: Lists for Radial Support Calculation

Element	A	L	Comment
1	.785398163	.75	'Cold_end
2	.196349541	9.7	'Note_1inch_for_LN2_intercept
3	0	0	
4	.196349541	6.8	'Warm_end
5	.785398163	.75	
6		18	

Radial Strap Calculation

A13

St	Input	Name	Output	Unit	Comment
					Program: Radial Strapping
		A%L	.27664073	cm	A/L to support bracket from strap
		Kinc	.10844258	W/cm	Thermal Conductivity Integral inconnel
	.03	Qbrac		W	Heat Load on Bracket
		Qstrap	.19121527	W	Heat Load on Strap
		Qtot	.22121527	W	Total Heat Load
	36	Ks		W/cmK	Thermal Conductivity of Strap
	5.1	Tc		K	Support Bracket Temperature
		Ti	14.156897	K	Intercept Temperature
	4.7	The		K	Temperature of Helium Tube side of str
	12	Ls		cm	Length of Strap
		As	.00673989	cm2	Area of Strap
		Ds	.09263634	cm	For a round strap
		Lsq	.08209682	cm	Side of a square strap
		Lrect	.01347978	cm	Long leg of a rectangular strap
	.5	Wrect		cm	Short leg of a rectangular strap
		KdT	3.6371404	W/cm	Thermal Conductivity Integral inconnel
	90	TN2i		K	Nitrogen Intercept Temperature
	.5	Drod		in	
		Arod	.19635595	in2	Area of support rod
	8.2	Lrod		in	Length of sup't rod between intercepts
		TL			used in Kproc1
		TU			used in Kproc1

Main Equations for Radial Strapping Calculation

S Rule

```
* A%L=AL()
* Kinc=dfnipoly(Tc,Ti,'Kpoly718)
* Qbrac=A%L*Kinc
* Qstrap=Qtot-Qbrac
* Qstrap=As/Ls*Ks*(Ti-The)
* KdT=dfnipoly(Ti,TN2i,'Kpoly718)
* Qtot=Arod/Lrod*KdT
* Arod=(Drod/2)^2*pi()
* Lsq=sqrt(As)
* Lrect=As/Wrect
* As=pi()/4*Ds^2
```

AL Routine for Radial Strapping Calculation

Comment: Determines A/L for cold end
Parameter Variables:
Input Variables:
Output Variables: A%L

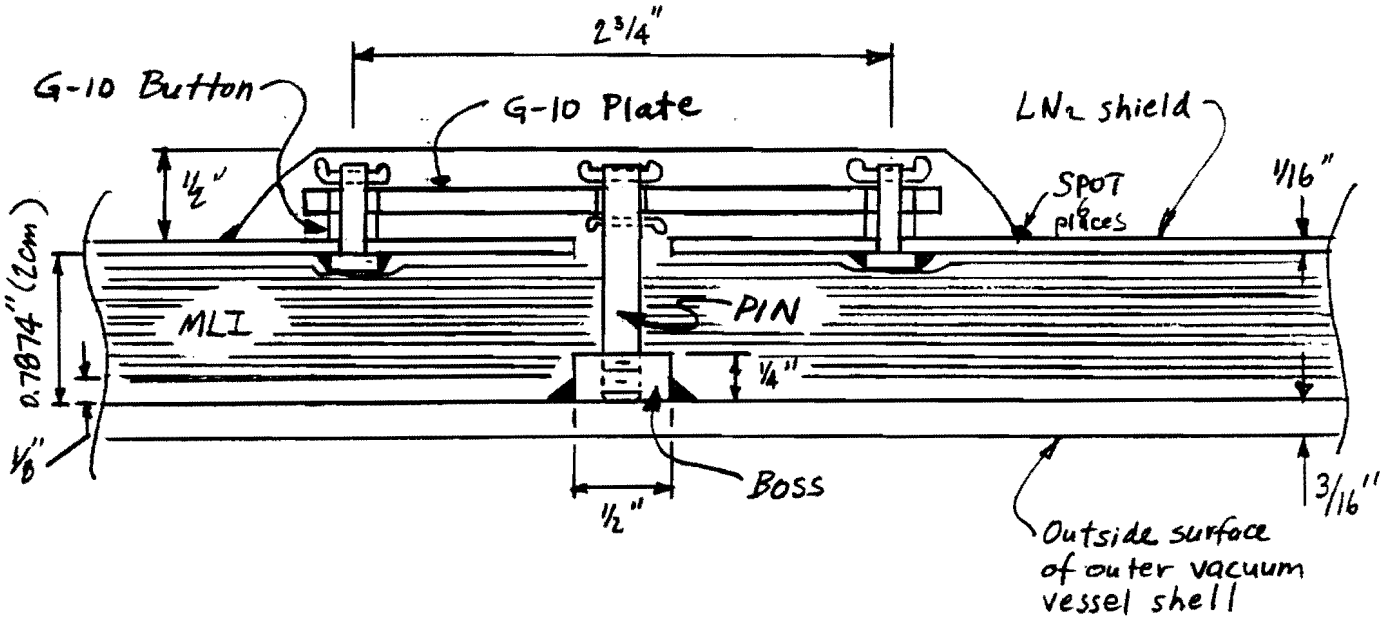
S Statement

```
A%L=((1-(11/16)^2)/4*pi()/(3/8)+pi()/4/0.5)*2.54

LAb=0.375/((1-(11/16)^2)/4*pi())   "ball on bracket
LAbs=0.5/(1*pi()/4)  "socket on ball
LAsr=1.5/(0.5^2/4*pi())  "rod on socket

A%L=1/(LAb+LAbs+LAsr)*2.54e-2
```

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		D0 SOLENOID		A16

SUBJECT	NAME	
LN_2 SHIELD STANDOFF - MODIFIED CDF TYPE HEAT LEAK CALCULATION	AMS/BS	
	DATE 4/28/93	REVISION DATE

SKETCH:



$T_H \equiv$ Temperature of vacuum shell = 300 K
$T_C \equiv$ Temperature of LN_2 shield = 80 K
Boss temperature = T_H = 300 K
Pin data: Material – Titanium alloy
Diameter – 0.5 cm
Thermal resistance length = 1.2 cm
Plate data: Material – G-10
Width – 3 cm
Thickness – 0.2 cm
Thermal resistance length –
Button data: Material – G-10
OD – N/A
ID – N/A
Thermal resistance length – N/A

} Ignore the button thermal resistance. Assume the end of the G-10 plate is at T_C = 80 K.

FERMILAB ENGINEERING NOTE	SECTION	PROJECT DØ SOLENOID	SERIAL-CATEGORY	PAGE A17
SUBJECT: LN_2 Shield Standoff Heat Load Calc.		NAME: AMS		
		DATE: Aug 6, 1993	REVISION DATE	

DO A ONE-DIMENSIONAL HEAT LEAK CALCULATION, $Q = \Delta T / \Sigma R$.

ASSUME A TIGHT FIT BETWEEN THE PIN, PLATE AND SHIELD. THIS IS A CONSERVATIVE ASSUMPTION BECAUSE THESE CONNECTIONS FIT LOOSELY.

PIN RESISTANCE:

ASSUME THE PIN IS SOLID. (IT DOESN'T HAVE TO BE.)

ASSUME THE PIN ΔT IS SMALL. USE k AT 300 K.

$k = 0.09$ W/cm-K

$$R_{PIN} = \frac{L}{Ak} = 1.2\ \text{cm} * \frac{4}{\pi (0.5)^2\ \text{cm}^2} * \frac{\text{cm K}}{0.08\ \text{W}} = 76\ \frac{\text{K}}{\text{W}}$$

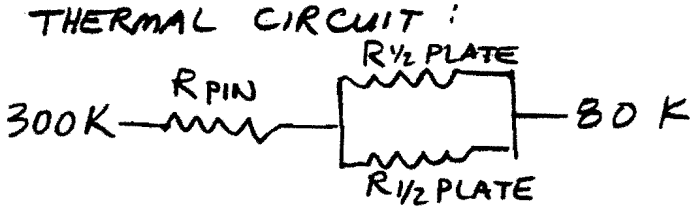
G-10 PLATE RESISTANCE:

$\bar{k} = 0.0064$ W/cm-K BETWEEN 300 K AND 80 K.

$$R_{1/2\ PLATE} = \frac{L}{Ak} = (2.75\ \text{in}/2) * 2.54\ \text{cm/in} * \frac{1}{(3*0.2)\ \text{cm}^2} * \frac{\text{cm-K}}{0.0064\ \text{W}}$$

$$= 910\ \frac{\text{K}}{\text{W}}$$

THERMAL CIRCUIT:



$$\Sigma R = R_{PIN} + \frac{(R_{1/2\ PLATE})^2}{2\ R_{1/2\ PLATE}} = 76\ \frac{\text{K}}{\text{W}} + \frac{910^2\ \text{K}^2/\text{W}^2}{2\ (910)\ \text{K/W}}$$

$$= 531\ \text{K/W}$$

$$q = \frac{\Delta T}{\Sigma R} = (300 - 80)\text{K} * \frac{\text{W}}{531\ \text{K}} = 0.4\ \text{W}$$

USE 1/2 W FOR EACH STANDOFF.

557421

Calculation for Heat Load from Charging Rate

St	Input	Name	Output	Unit	Comment
		R	3.0019E-6	ohm	Support Cylinder Resistance
		R1	3.2332E-6	ohm	Support Cylinder Resistance
		R2	4.1959E-5	ohm	End Rings resistance
	1010	N1		turns	Coil Turns
	.65	r		m	Mean Radius of Coil
	2.56	l		m	Length of Coil
	2.6	lc		m	Length of Cylinder
	15	thick		mm	Thickness of Cylinder
	.658	rc		m	Mean Cylinder Radius
	1	N2		turns	Support Cylinder Turns
	47.7	thicke		mm	End ring thickness
	15	le		mm	end ring length
		A	1.3273229	m2	Area of Coil
		μ	1.2566E-6	H/m	
	3.05E-8	rho		ohm-m	Resistivity of Support Cylinder
		M	.00065806	Henry	Mutual Inductance
	12	didt		amp/s	
		P	20.773092	Watt	Heat Load

Equations for Charging Load Calculation

S Rule

P=M^2/R*didt^2
M=μ*N2/l*A*N1
μ=4*pi()*10^-7
A=pi()*r^2

R1=rho*rc*2*pi()/thick/lc
R2=0.5*rho*(rc-thick/2-thicke/2)*pi()/thicke/le
R=1/(1/R1+1/R2)

Reference: R.W. Fast, "Transient Heat Load to Outer Support Cylinder from Eddy Currents", SDC Solenoid Design Note #119, Nov. 7, 1990.