DØ SOLENOID UPGRADE PROJECT

**Heat load calculations
for
the solenoid Chimney**

D-ZERO ENGINEERING NOTE # 3823.111- EN-344

May 26, 1993

Russ Rucinski

This engineering note documents the calculations done to determine the chimney heat loads. These heat load numbers were reported in the DØ solenoid upgrade design report.¹ The table that summarizes the heat loads is below.

Table 5.3: Heat Loads for the Chimney

ITEM	HEAT LOAD 300 K to 80 K	HEAT LOAD 80 K to 4.5 K
Radiation, obround section	13.6 W	123 mW
Radiation, circular section	86.4 W	780 mW
Field joints (4)	-----	100 mW
G-10 supports (10)	7.6 W	440 mW
TOTAL	108 Watts	1.5 Watts

The heat loads to the LN2 circuit were done by Andrew Stefanik, RD/Mechanical Systems group. They were part of his LN2 shield calculations dated 2/23/93. Pages 1 thru 3 of his calculations that apply to the chimney are attached.

The heat loads to the LHe circuit were done originally on 12/16/92 and then revised on 12/23/92 to be more conservative. The raw calculations are attached. I include both the original 12/16 version and the 12/23 revised version to document the amount of conservativeness added.

¹ DØ Solenoid design report draft chapter 5, 5/20/93, authored by Russ Rucinski.

SUBJECT

SUPPLY LINE

NAME

DATE

Feb 25, 1993

REVISION DATE

1. SIZE: $\frac{1}{2}$ " OD TUBE $\times$ 0.065" wall
(CDF size: 12mm OD $\times$ 2mm wall $\approx$ 0.5" OD $\times$ 0.0787" wall)
Warm id = $0.5" - 2(0.065) = 0.37"$
2. LENGTH: (BASED ON R. RUCINSKI CHIMNEY CALCS DATED 1/8/93.)
 $12" + 69" + 138" + 69" + 38" + 38" + 38" + 12" + 12" + 36" + 36" + 9" + 9" + 24" = 540" = 45'$
3. RESISTANCE COEFFICIENT FOR MINOR LOSSES: (BASED ON R. RUCINSKI CHIMNEY CALCS DATED 1/8/93.)

No. OF 90° SHORT RADIUS ELBOWS $\approx$ 10

$$K_{\text{pipe}} = 10(20 \text{ ft}) = 10(20)(0.027) = 5.4$$

$$K_{\text{tee}} = 5.4 \left(\frac{0.37}{0.622} \right)^4 = 0.7$$

No. OF TEE BRANCHES = 2

$$K_{\text{pipe}} = 2(60 \text{ ft}) = 2(60)(0.027) = 3.24$$

$$K_{\text{tee}} = 3.24 \left(\frac{0.37}{0.622} \right)^4 = 0.4$$

$$\Sigma K = 0.7 + 0.4 = 1.1$$

4. CHIMNEY HEAT LEAK

• SHIELD -

ASSUME A CIRCULAR SHIELD FOR THE ENTIRE LENGTH.

O.D. = 6.625" (FROM R. RUCINSKI)

$$\text{SURFACE AREA} = \pi (6.625/12)' \times 45' \approx 80 \text{ ft}^2$$

THE SHIELD IS WRAPPED WITH ALUMINUM TAPE. THE VACUUM JACKET IS STAINLESS STEEL PIPE.

$$\frac{Q}{A_1} = F_{1-2} \sigma (T_1^4 - T_2^4)$$

1 $\equiv$ SMALLER SURFACE AT 78 K2 $\equiv$ LARGER SURFACE AT 300 K

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ENGINEERING NOTE

SECTION

PROJECT

SERIAL-CATEGORY

PAGE

2

SUBJECT

NAME

AMS

DATE

Feb 25, 1993

REVISION DATE

$$f_{1-2} = \frac{1}{\frac{1-\epsilon_1}{\epsilon_1} + 1 + \frac{A_1(1-\epsilon_2)}{A_2\epsilon_2}} \quad \text{FOR CONCENTRIC CYLINDERS}$$

$$\epsilon_1 = 0.03$$

$$\epsilon_2 = 0.85 - \text{Weathered}$$

$$A = \pi d l$$

$$\frac{A_1}{A_2} = \frac{\pi d_1 l}{\pi d_2 l} = \frac{d_1}{d_2} = \frac{6.625''}{8.329''} = 0.8$$

8" SCH 10S

$$f_{1-2} = \frac{1}{\frac{1-0.03}{0.03} + 1 + \frac{0.8(1-0.85)}{0.85}} = 0.03$$

$$Q/A_1 = 0.03 \left(5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4} \right) (300^4 - 78^4) \text{ K}^4$$

$$= 13.7 \text{ W/m}^2 = 1.274 \text{ W/ft}^2$$

$$Q = 1.274 \text{ W/ft}^2 \times 80 \text{ ft}^2 = 102, \text{ SAY } 100 \text{ W}$$

SUPPORTS

THERE ARE 6 G-10 SUPPORTS.

ASSUME 4-1/2" x 1/8" WALL G-10 RODS FOR EACH SUPPORT.

$$Q = \frac{A}{l} \int k(T) dT$$

ASSUME 2 OF THE 4 RODS MAKE GOOD THERMAL CONTACT.

$$A_{\text{supt}} = \frac{\pi}{4} (0.5^2 - 0.25^2) \times 2 = 0.295 \text{ in}^2 = 1.9 \text{ cm}^2$$

$$l = (8.329'' - 6.625'')/2 = 0.852 \text{ in} = 2.164 \text{ cm}$$

$$\int_{78}^{300} k(T) dT = 1.4 \text{ W/cm}$$

$$Q_{\text{supt}} = \frac{1.9 \text{ cm}^2}{2.164 \text{ cm}} \times 1.4 \frac{\text{W}}{\text{cm}} = 1.23 \text{ W}$$

$$Q \text{ FOR 6 SUPPORTS} = 1.23 (6) = 7.4 \text{ W}$$

(3)

SUBJECT

NAME
AMSDATE
Feb 25, 1993

REVISION DATE

PIPE STOP

ASSUME 2 - 1/4" ϕ SS RODS, FEET LONG

$$Q = \frac{A}{l} \int k(T) dT$$

$$A = 2 \left[\pi \frac{(0.25")^2}{4} \right] = 0.1 \text{ in}^2 = 0.63 \text{ cm}^2$$

$$l = 3 \text{ ft} = 91.44 \text{ cm}$$

$$\int_{78}^{300} k(T) dT = 27.43 \text{ W/cm}$$

$$Q = \frac{0.63 \text{ cm}^2}{91.44 \text{ cm}} \times 27.43 \frac{\text{W}}{\text{cm}} = \underline{0.2 \text{ W}}$$

$$\bullet \text{ TOTAL HEAT LOAD} = 100 + 7.4 + 0.2 = 107.6 \text{ W}$$

$$\bullet \text{ UNIFORM HEAT LOAD/FOOT OF PIPE} = \frac{107.6 \text{ W}}{45 \text{ ft}} = 2.4 \text{ W/ft}$$

• CHECK THE 2.4 W/ft NUMBER:

IN THE CVI CATALOG, THE HEAT LEAK FOR AN MLI, 6"X8" LN₂ LINE $\approx 1.657 \text{ Btu/hr-ft} = 0.49 \text{ W/ft}$.

ASSUME THE HEAT FLUX TO A MLI INSULATED SHIELD IS $\sim 2 \text{ W/m}^2$ FOR THIS APPLICATION.

$$\text{THE SHIELD HEAT LEAK IS} = \frac{2 \text{ W/m}^2}{13 \text{ W/m}^2} \times 96.6 \text{ W} \approx 15 \text{ W}$$

$$\begin{aligned} \text{THE UNIFORM HEAT LOAD/FOOT OF PIPE} &= \frac{15 + 7.4 + 0.2}{45} = \frac{22.6}{45} \\ &= 0.5 \text{ W/ft} \end{aligned}$$

THE 0.5 W/ft RESULT COMPARES WELL WITH THE CVI PUBLISHED, ESTIMATED DATA.

HEAT LOAD TO LHE FOR TRANSFER LINE:REV. 12/23/92 Δ

- RADIATION HEAT LOAD 77K TO 4.2K

USE $q'' = 20 \text{ mW/m}^2$ ^{IDEAL} PER: "TECHNIQUES FOR REDUCING"

IF $q'' = 150 \text{ mW/m}^2$ Δ

AMS CALCS. 150 mW/m² FOR CDF Δ 10/7/92

CDF SOL.
HEAT LEAK

~~RADIATION HEAT TRANSFER~~

~~B/W 77 & 4.2K. R.W. FASTEST.~~

$$\text{AREA: } \overline{AB} = (\text{PERIMETER}) \times (\text{LENGTH}) = 12 \text{ W.} \times 106 \text{ IN.} = 1272 \text{ IN}^2 \\ = 0.821 \text{ m}^2$$

$$q_{\text{RAD AB}} = 16.4 \text{ mW} \text{ OR } 1.86 \text{ mW/FE.} \quad \Delta$$

123 mW BASED ON CDF CALC.

$$\text{AREA: } \overline{BC} \text{ \& } \overline{CD} = (P)(L) = \pi(6.625 \text{ IN.})(114 \text{ IN.} + 274 \text{ IN.}) \\ = 8066 \text{ IN}^2 = 5.20 \text{ m}^2$$

$$q_{\text{RAD BC \& CD}} = 104 \text{ mW} \text{ OR } 3.22 \text{ mW/FE} \\ 780 \text{ mW BASED ON CDF } \Delta$$

- FIELD JOINT, ^{RESISTIVE} HEATING $= 65 \text{ mW}$

ASSUME 1 IN. / JOINT

$$Q = I^2 R = (5000 \text{ AMPS})^2 (1 \times 10^{-7} \Omega) = .025 \text{ W}$$

25 mW
4 JOINTS

{ REF. $\frac{1}{4}$ OF 0.26 W FOR }
16 JOINTS LISTER IN
CDF DESIGN REF. Δ

- 6-10 SUPPORTS

USE 55 mW / SUPPORT

{ REF. D. BELL GRAPHICAL T PROFILE }
& R.A.R. QUICK CALC.

ASSUME 8 SUPPORTS

$$\therefore q_{\text{6-10 SPIDERS}} = 440 \text{ mW} \quad \checkmark \text{ CONFIRM BY IDENTIFY POSSIBLY}$$

TOTAL HEAT LOAD TO BOTH LHE LINES IN
TRANSFER LINE IS:

$$q_{\text{TOTAL}} = 123 \text{ mW} + 780 \text{ mW} + 100 \text{ mW} + 440 \text{ mW} \quad \Delta \\ = 16.4 \text{ mW} + 104 \text{ mW} + 65 \text{ mW} + 440 \text{ mW} \\ = 625 \text{ mW} \approx 0.63 \text{ W} \quad * \\ 1443 \text{ mW} \approx 1.5 \text{ W} \quad \Delta$$

* NOTE: THERE IS NO MULTIPLICATION
FACTOR ON THIS NUMBER
TO COMPENSATE FOR REAL
WORLD CONSTRUCTION.

HEAT LOAD TO LHE FOR TRANSFER LINE:

- RADIATION HEAT LOAD 77K TO 4.2K

USE $q'' = 20 \text{ mW/m}^2$ PER; "TECHNIQUES FOR REDUCING"
RADIATION HEAT TRANSFER
B/W 77 & 4.2K. R.W. FAST ET AL.

$$\text{AREA: } \overline{AB} = (\text{PERIMETER}) \times (\text{LENGTH}) = 12 \text{ W.} \times 106 \text{ IN.} = 1272 \text{ IN}^2 \\ = 0.821 \text{ m}^2$$

$$q_{\text{RAD}}^{\overline{AB}} = 16.4 \text{ mW} \quad \text{OR} \quad 1.86 \text{ mW/FT.}$$

$$\text{AREA: } \overline{BC} \approx \overline{CD} = (P)(L) = \pi(6.625 \text{ IN.})(114 \text{ IN.} + 274 \text{ IN.}) \\ = 8066 \text{ IN}^2 = 5.20 \text{ m}^2$$

$$q_{\text{RAD}}^{\overline{BC} \& \overline{CD}} = 104 \text{ mW} \quad \text{OR} \quad 3.22 \text{ mW/FT.}$$

- FIELD JOINT, ^{RESISTIVE} HEATING = 65 mW } REF.
 } 1/4 OF 0.26W FOR 16 JOINTS LISTED IN CDF DESIGN RPT.

- G-10 SUPPORTS

USE 55 mW / SUPPORT } REF. D. BELL GRAPHICAL T PROFILE & R.A.R. QUICK CALC. }

ASSUME 8 SUPPORTS

$$\therefore q_{\text{G-10 SPIDERS}} = 440 \text{ mW}$$

TOTAL HEAT LOAD TO BOTH LHE LINES IN TRANSFER LINE IS:

$$q_{\text{TOTAL}} = 16.4 \text{ mW} + 104 \text{ mW} + 65 \text{ mW} + 440 \text{ mW} \\ = 625 \text{ mW} \approx 0.63 \text{ W} *$$

* NOTE: THERE IS NO MULTIPLICATION FACTOR ON THIS NUMBER TO COMPENSATE FOR REAL WORLD CONSTRUCTION.