Flexible Support

Liquid Argon Heat Intercept

D-Zero Engineering Note 3740.214-EN-75

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Approved

Introduction

A device in the flexible support system for the Central Calorimeter is the Liquid Argon Heat Intercept. The purpose of this apparatus is to intercept heat outside the inner vessel so that bubbles do not form inside. If bubbles did happen to form inside the vessel, they would cause an electric arc between the read-out board and the absorption plates, thus destroying the pre-amplifier. Since this heat intercept is located in the center of the flexible support, it must also support the load of the Central Calorimeter. Figure 1 shows how the intercept works. The subcooled liquid argon is driven through a $1/4" \times 0.049"$ tube by hydrostatic pressure. The ambient heat boils the subcooled argon. The gaseous argon flows through the tube and is condensed at the top of the vessel by a 100 kW cooling coil. This process is present in all four flexible support systems. Drawing 3740.214-MD-225237, shows the heat intercept in detail.

Figure 1 Heat Intercept Process

Heat Transfer

Heat Intercepted

If the intercept was not present, 136.51 Blu/hr (40 watts) of energy per support would be transferred to the liquid argon inside the inner vessel. (See Engineering Note 3/40.214-LN 71). With the use of an intercept, this energy is carried away by a small flow of subcooled argon.

The intercept is a stainless steel disc with a curved trough machined through it, with a stainless steel cap welded on that. The liquid argon will pass through the cross section of figure 2.

Figure 2 Cross-Section of Intercept Trough

The length of the groove is **23.066 inches**, and the perimeter of the cross section measures **1.7854 inches**. The surface area in contact with the liquid argon is **41.182 in²**.

From Reference 5, the maximum heat load carried away by the intercept is bounded by the minimum heat flux on the argon pool boiling curve. If the amount of heat that is transferred to the intercept is less than the one calculated from the pool boiling data, there will be no substantial heat leak to the inner vessel. Appendix 1 shows the calculations that estimates the minimum heat flux for argon.

Therefore;

$$Q=q \cdot A$$

Where

Q=Heat Transferred

q*= Heat Flux

A= Surface Area

Therefore the maximum ammount of energy that can be carried away is **5.462×10^2 BTU/hr (160.304 Watts)**. All of the heat that is supplied from the ambient (40W) is used to boil the liquid argon.

Heat Transfer to Vessel

At thermal equilibrium, the heat intercept will be approximately 5 degrees higher than the liquid argon flowing through it. Since this temperature is approximately 10 degrees higher than the subcooled argon at the bottom of the inner vessel, heat will always be transferred to the subcooled argon.

Figure 3 Heat Transfer to Vessel

The heat transferred may be determined by:

$$Q' = (A/L) \int K dT$$

Where:

Q=Heat transferred

A=Cross sectional area

L=Length of support

K=Thermal conductivity

dT=Change in temperature

From Engineering note 3/40.222-EN-73, the length of support and the cross sectional area for the G-10 support disc are 1 inch and 0.164 ft², respectively. From reference 4, the $\int K dT$ between 85 K and 95 K (Figure 3), is calculated to be 0.2709 BTU/Hr in. Therefore, the heat transferred to the inner vessel is 6.398 BTU/Hr (1.87 W).

Tube Size

Bubble Mass Flow

1/4" OD x .049 w. tube is used to transfer the argon to and from the argon heat intercept. Drawing number 3/40 214-ME-223235 shows the tube orientation and placement.

To find the mass flow per support;

$$Q = m h_{fg}$$

Where

Q = Heat Transferred = 136.51 BTU/Hr

m = Mass flow required

h_{fg} = Heat of Vaporization = 0.0705 BTU/lb °F @ 90K

The mass flow of gaseous argon is 5.51×10^{-4} lb_m/s.

Minimal Head

The head of argon in the inner vessel must be kept above a minimal level to assure enough pressure is present to boil away 5.51×10^{-4} lb_m/s of argon. If the head goes below this level, bubbles may form inside the inner vessel.

Figure 4 Vessel Sketch

From Bernoulli's equation

$$\frac{P_1}{\rho_1} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho_2} + \frac{V_2^2}{2g} + Z_2$$

Where

P=Pressure

V=Velocity

Z=Height

ρ =Density of liquid argon=0.05 lb_m/in³

g=32.17 ft/s² = 386 in/s²

Solving for Z_2

$$Z_2 = -(V^2/4g)$$

Where

$$V = Q/A = m/\partial A = 0.358 \text{ in/s.}$$

Therefore

$Z = 8.3 \times 10^{-5}$ inches above the level of the support. (This is for an ideal case, since no pressure drop in the pipe line was taken into account.)

Pressure Drop

Inlet Line

As flow starts, subcooled liquid argon enters the intercept. The pressure drop must be a minimum to keep the flow of liquid to the intercept continuous (As gaseous argon leaves the intercept, liquid argon enters it.). From Reference 2;

$$\Delta P/L = fG^2/2g\partial D$$

Where

$\Delta P/L$ = Pressure drop per unit length of pipe

f = friction factor

$G = m/A$

A = pipe crosssectional area 0.0309 in^2

m = flow rate $= 5.51 \times 10^{-4} \text{ lb}_m/\text{s}$

$g = 32.174 \text{ ft-lb}_m/\text{lb}_f\text{-s}^2$

∂_l = density of liquid argon $= 86.91 \text{ lb}_m/\text{ft}^3$

∂_g = density of gaseous argon $= 0.360 \text{ lb}_m/\text{ft}^3$

D = inner diameter of tube $= 0.152 \text{ in}$

$$R_e = DG/\mu$$

Where

R_e = Reynold's number

μ_l = viscosity of liquid argon = $0.57 \text{ lb}_m/\text{hr-ft}$

μ_g = viscosity of gaseous argon = $0.01797 \text{ lb}_m/\text{hr-ft}$

R_e is calculated to be **205.42** making the flow laminar; therefore, the friction factor, $f = 64/R_e = 0.3116$, making the change in pressure equal to **$2.0141 \times 10^{-4} \text{ psi/ft}$** . Approximately 2.6 feet of tubing connect the intercept and the liquid argon outlet, therefore the total pressure drop in the inlet line is **$5.2367 \times 10^{-4} \text{ psi}$** .

Outlet Line

The pressure drop in the tubing past the intercept must be lower than the hydrostatic head or the gas will flow back into the inner vessel. Using the formulas from above and assuming all gas after the intercept, $R_e = 6515.9$, making the flow turbulent. From reference 2, $f = 0.316 R_e^{-0.25} = 0.0352$. From the numbers for gaseous argon the pressure drop becomes **0.0055 psi/ft** . There is approximately 20 feet of tubing after the intercept, therefore the total pressure drop after the intercept is **0.11 psi** .

The hydrostatic head is **$\Delta z = 9.6567 \text{ psi}$** . The pressure drops calculated are sufficiently lower than this head.

Condensation of Argon

At the top of the inner vessel will be a 100 kW cooling coil. This coil will cool the gaseous argon at the same rate the ambient heats the liquid argon. This will alleviate any major pressure or volumetric changes in the gas and liquid argon.

Stresses

Compressive stress

Approximately **100 tons** is the load seen on each support; therefore, this is the compressive force exerted on each intercept.

$$S=P/A$$

Where;

S=Compressive Stress

P=Load on intercept=**200,000 pounds**

A=Compressive Area= $\pi d^2/4$ - length of groove*thickness
= 23.758 in² - 23.066(0.5) = 12.225 in²

From this, the compressive stress is **16359.9 psi**. From Reference 3, the yield and ultimate strengths for 304 Stainless Steel are 35 ksi and 85 ksi, respectively, giving a factor of safety of **2.14** on yield and **5.196** on ultimate strength. A.I.S.C states that the allowable stress in compression is **0.6 F_y**; therefore, the allowable stress to satisfy the code is **21000 psi**.

Shear Stress

According to Engineering Note 3740-214-EN-71, the shear force exerted on the intercept is **33976 lbs**. For the intercept, the compressive area is the same as the shear area, therefore the shear stress in the intercept is **2779.2 psi**. This gives a factor of safety of **12.6** on yield and **30.58** on ultimate. A.I.S.C. states that the allowable stress in shear is **0.4 F_y**; therefore the allowable stress to satisfy the code is **14000 psi**.

Conclusion

The Liquid Argon Heat Intercept reduces the 136.485 BTU/Hr (40 W) from the ambient to 6.398 BTU/Hr (1.87 W) by continuously boiling argon at a rate of 5.51×10^{-4} lb_m/s. The 1/4 OD x 0.049w. tubing carries the liquid and gaseous argon through the system with a total pressure drop of 0.1105 psi. A 100 kW cooling coil condenses the argon at the rate the ambient boils it. The Intercept has a factor of safety of 2.14 on yield for compression and 12.6 on yield for Shear.

References

- 1.) Sample Design of Cryostat and Transporter, CBI, University of Pennsylvania, Physics Department, October 1986.
- 2.) Cryogenic Systems, Randall Barron, Oxford Science Publication, Second Edition, 1985.
- 3.) Ryerson, Stocklist and Data Book, 1985-86 Edition.
- 4.) Mechanical, Electrical, and Thermal Characterization of G-10CR and G-11CR, glass-cloth/ epoxy laminates between room temperature and 4K, M.B. Kasen, et al, National Bureau of Standards, D-1
- 5.) Fundamentals of Heat and Mass Transfer, Frank P. Incropera and David P. DeWitt, John Wiley and Sons Inc., 1985

Appendix 1

Minimum Heat Flux Calculation

From Page 468 of Reference 5

$$g'_{min} = C f_v h_{fg} \left[\frac{90 (P_L - P_v)^{7/4}}{(P_L + P_v)^2} \right]$$

Comparing this formula to the data from Reference 1 Figure 5 - Nitrogen Data

$C = .09$ - Empirically determined constant

$$P_L = 807.3 \text{ kg/m}^3$$

$$h_{fg} = 199.3 \text{ kJ/kg}$$

$$P_v = 4.604 \text{ kg/m}^3$$

$$\sigma = 8.75 \times 10^{-3} \text{ N/m}$$

$$g'_{min} = .09 (4.604) (199.3 \times 10^3) \left[\frac{9.8 (8.75 \times 10^{-3}) (807.3 - 4.604)^{7/4}}{(807.3 + 4.604)^2} \right]$$

$$= \underline{0.8348 \text{ W/cm}^2}$$

Reference 1 Estimate $g'_{min} = .640$

Scaled Constant: $C_s = .0689986$

Argon Estimate

$$P_L = 1393.9 \text{ kg/m}^3$$

$$h_{fg} = 161.9 \text{ kJ/kg}$$

$$\sigma = 11.02 \times 10^{-3} \text{ N/m}$$

$$P_v = 5.767 \text{ kg/m}^3$$

$$g'_{min} = .0689986 (5.767) (161.9 \times 10^3) \left[\frac{9.8 (11.02 \times 10^{-3}) (1393.9 - 5.767)^{7/4}}{(1393.9 + 5.767)^2} \right]$$

$$= 0.60335 \text{ W/cm}^2 = \underline{3.28 \text{ Btu/hr in}^2}$$

Figure 5

Figure 17. Typical pool boiling characteristic curve.

NOT FOR CONSTRUCTION

SAMPLE DESIGN

211-N/UTB V/b

REV A

ECB

N 6012

9/22/86

SH

5-7

211-N/UTB V/b

200

12

PK