Theoretical analysis and experimental investigation on performance of the thermal shield of accelerator cryomodules by thermo-siphon cooling of liquid nitrogen

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CRYOGENIC SYSTEM

He Refrigerator

VALVE BOX

CRYO LINE

PELLETRON

SUPERBUNCHER

LINAC CRYOSTAT

REBUNCHER

QWR Nb Cavity (97 MHz)

$\text{Ti}_{48} + ^{14} = 160 \text{ MeV}$

$\text{Ti}_{48} + ^{14} = 270 \text{ MeV (310)}$

Thermal Shield

CEC-ICMC 2015, Tucson (June 30, 2015), T S Datta
MAIN CRYOMODULES

1. BEAM LINE & CRYOSTAT VACUUM COMMON. $10^{-8}$ TORR. NO MLI

2. 80 K THERMAL SHIELD BY LN2

LINAC CRYOMODULE

Superbuncher & Rebuncher Cryomodule
80 K THERMAL SHIELD

1. Forced flow of Liquid nitrogen

Outlet Two Phase Flow (Linac Cryostat)

2. Gravity (Thermo-siphon) flow

Optimized Use of LN2 (Buncher)

Contact Resistance (0.8 K/W)

\[
T_s = T_f + Q \left( \frac{1}{h_{tot} A_C} + \frac{R_C}{N} \right)
\]

Shield Temp

Fluid Temp (80K)

Heat Load

\[ = Sh_{nb} + Fh_{tp} \]

\( f(m) \)
SHIELD PERFORMANCE OF BUNCHER

BUNCHER CRYOSTAT

Temperature (K)/LN2 Level

Time (hr.)

Shield Temperature variation with Liquid Level in Buncher Cryostat

ΔT = 40 K

BUNCHER CRYOSTAT

LN2 Level (%)

NO THERMOSIPHON

NO LIQUID

T Shield

T Vessel

LN2 Level

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\[ \Delta p_d = \Delta p_f + \Delta p_a \]

\[
\Delta p_d = g(H + h - h_1)(\rho_l - \rho_{tp}) - gh_2\rho_{tp}
\]

\[
m \propto Q
\]

\[
g(H + h - h_1)(\rho_l - \rho_{tp}) - gh_2\rho_{tp} = \\
m^2 \left[ (h + h_1 + L) \frac{f_l}{2A_c^2 D \rho_l} + (h - h_1 + h_2)(1 - x)^{1.75} \phi_l^2 \frac{f_l}{2A_c^2 D \rho_l} + v_{fg} x \right]
\]
Superbuncher: Load is 100 W, Flow rate (m) of LN2 is very high and Convective resistance will be much less compared to Contact resistance

With liquid level (H) variation, mass flow rate (m) changes only 10%, Practically $T_s$ should not change with level. But $T_s$ with level (H) is noticed in superbuncher !!!

What is the reason ??
Thermo-Siphon Experimental set up was developed

1. On line Venturi flow meter did not work. Mass flow rate was measured indirectly by LN2 level meter
2. Normal evaporation rate and any change of flow rate was measured by Dry Gas Flow meter
3. Temperature was recorded by DT 470 sensor
4. Heater power (6 & 4 ohm) varied by two independent power supply
**Observation**

1. Mass flow rate \( m \) is much less than theoretical value
2. Heat load \( q \) on Down-stream pipe have significant effect on \( m \)
Analysis: Measured Mass flow rate (m) is much less compared to theoretical value

Reason

1. Quality changes and hence pressure drop in the pipe after the top plate
2. Some minor amount of heat load (q) on upstream, driving force is reduced because of low density
3. Measured Value matches with $h_2=5m$
Analysis of Shield Temperature

Mass flow rate with \( h_2 = 5 \) m and equal heat load \( Q=q \) shows a variation from 4 to less than 1 g/s with LN2 level.

Two phase flow will be in the annular zone and convective two phase (\( h_{tp} \)) heat transfer coefficient play a role.

Conclusion

1. Down-stream minor heat load have significant effect reduction on thermo siphon mass flow rate and hence thermal efficiency of the shield.

2. Modified design with the repositioning of the clamps will improve...