Implementation of multilayer insulation technique for detector cryogenics

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Introduction

Multilayer insulation (MLI) is an important technique to reduce the radiation heat load in a cryostat (a double walled container with the vacuum space between the two walls). For the continuous and authentic functioning of a cryostat, a minimum heat load is required to the inner (cold) wall of the cryostat [1]. The basic concept of MLI technique is to obtain the multiple radiation reflection by placing the reflective layers called radiation shields, in between the walls of the cryostat. These reflective layers are formed with thin polyethylene or Mylar sheet, coated with highly reflecting material (Aluminium or Gold) on both the sides. Therefore, low conductivity materials (or insulators) called spacers are placed in between these reflective layers to avoid the conduction due to adjacent reflective layers.

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Formulation for Heat exchange

Due to the environmental effects, there are three types of heat loads in a cryostat: Thermal radiation, Solid conduction and Residual gas conduction [2], in which thermal radiation is the major part of the total produced heat load.

The present work focuses on the reduction of thermal radiation and the selection of the best MLI material. For the analysis, perforated double−Aluminized Mylar (DAM) with Dacron, unperforated DAM with Silk−net and perforated DAM with Glass−tissue are selected as the reflective layer as well as spacer materials and used Modified Lockheed equation for Silk−net and Glass−tissue which is given by the expression (1)

$$q_{\text{total}} = \frac{C_R\ \varepsilon\ (T_h^{4.67} - T_c^{4.67})}{N} + \frac{C_S\ \bar{N}^{2.63}(T_h - T_c)(T_h + T_c)}{2\ (N+1)} + \frac{C_G\ P\ (T_h^{0.52} - T_c^{0.52})}{N} \quad , \quad (1)$$

where $\bar{N}$ and N is the layer density and number of layers. The symbol C_S, C_R and C_G are empirical constants and denotes solid conduction coefficient, radiation coefficient and gas conduction coefficient respectively. Here T_h and T_c are the temperatures (in K) of the outer (hot) and inner (cold) wall of the cryostat, ε is the emissivity of the radiation shields and P is the residual gas pressure [1].

After modifying the "solid conduction" term for Dacron, the total heat load becomes

$$q_{\text{total}} = \left(\frac{2.4 \times 10^{-4}(0.017 + 7 \times 10^{-6}\ (800 - T) + 0.0228\ ln(T))\ \bar{N}^{2.63}(T_h - T_c)}{N} \right) + \left(\frac{C_R\ \varepsilon\ (T_h^{4.67} - T_c^{4.67})}{N} \right) + \left(\frac{C_G\ P\ (T_h^{0.52} - T_c^{0.52})}{N} \right), \quad (2)$$

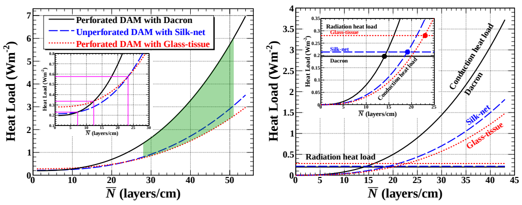

FIG. 1: Variation in the heat load with $\bar{N}$ for a constant $N = 40$ in the left panel and Optimum value of $\bar{N}$ for a constant value of $N = 40$ in the right panel.

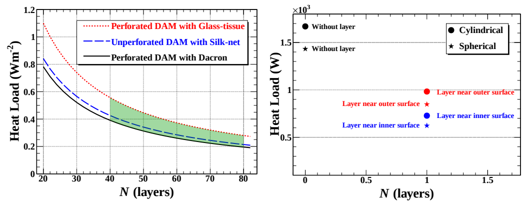

FIG. 2: Variation in the heat load with N at calculated $\bar{N}$ in the left panel and Comparison of the heat load for the two shapes of a cryostat in the right panel.

where T is the average temperature $\left(T = \frac{T_h + T_c}{2}\right)$ of the hot and cold boundaries.

Results and discussion

Numerous approaches have been tested by choosing the value of ε to be 0.043 DAM [3], $P = 10^{-4}$ torr, $T_c =$ 77 K for liquid nitrogen (LN_2) and $T_h =$ 300 K for water, respectively. The values of all the empirical constants are as follows: for Unperforated DAM with Silk−net ($C_R = 5.39 \times 10^{-10}$, $C_S = 8.95 \times 10^{-8}$ and $C_G = 1.46 \times 10^{-4}$), for Perforated DAM with Glass−tissue ($C_R = 7.07 \times 10^{-10}$, $C_S = 7.30 \times 10^{-8}$ and $C_G = 1.46 \times 10^{-4}$) and for Perforated DAM with Dacron ($C_R = 4.94 \times 10^{-10}$, $C_S =$ Shown in (2) and $C_G = 1.46 \times 10^{-4}$).

Increasing the value of $\bar{N}$ at fixed value of $N = 40$, within a fixed thickness of MLI blanket results in the increment of the heat load for all the selected materials [2], which is shown in the left panel of figure 1. Increasing the value of $\bar{N}$ beyond the optimal limit, solid conduction increases between the radiation shields. Whereas, the radiation heat load remains invariant. Therefore, the optimization of layer density is required and is presented in the right panel of figure 1.

After the evaluation of optimum values of $\bar{N}$, we quantify the effect of increment in the value of N over the heat load, with increasing the thickness of the MLI blanket, at the constant calculated value of $\bar{N}$. A decrement in the heat load is analyzed and the result is shown in the left panel of figure 2. The radiation exchange between two surfaces of the cryostat depends on the geometry of the cryostat. Here the heat load is compared by using the cylindrical and spherical shape of the cryostat, with and without MLI technique and the result is shown in the right panel of figure 2.

Acknowledgments

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References

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