CRACK COVERING PATCH TECHNIQUE TO REDUCE THE HEAT FLUX FROM 77 K TO 4.2 K THROUGH MULTILAYER INSULATION*

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Abstract

The effects of cracks in a multilayer insulation blanket on the heat load from 77 K to 4.2 K is a serious problem, but less so than from room temperature to 77 K. The technique of patching the cracks and the enhanced black cavity model developed to reduce heat flux through cracks in a MLI blanket to a 77 K surface were applied to the 77-4.2 K situation. The optimized patch covering technique is also very effective in this temperature region. The heat load through cracks in a MLI system between 77 K and 4.2 K, calculated by means of the enhanced black cavity model, is in agreement with the experimental data.

The temperature distributions were measured, and the corresponding equivalent thermal conductivity of the crack were deduced. Both of these quantities were quite different from those measured at higher temperatures.

INTRODUCTION

The theory and techniques to reduce the effects of cracks in MLI insulation on the heat load from room temperature to 77 K have been investigated experimentally.[1,2] It was a conclusion of that study that cracks in a MLI blanket seriously degrade the thermal performance and cause an unexpectedly large heat load through the insulation system. It was also noted that an optimized crack-covering technique could improve the thermal performance of a MLI system with cracks to that without cracks in that temperature region. It is well known that there are three heat transfer mechanisms in MLI systems: residual gas molecular conduction, radiation, and solid conduction between the adjacent layers. The relative importance of each is a function of temperature. Because of the low heat of vaporization of liquid helium, any degradation of the MLI on superconducting devices can have serious operational consequences. It was obvious, therefore, that the effect of cracks on the heat load from 77 K to 4.2 K should be examined and patches applied to the cracks to achieve reduced heat leak.

Since we believed that the basic results of the earlier study might be generally applicable to the 77-4.2 K temperature region, only a single crack width and a single patch geometry were tested between 77 K and 4.2 K.

EXPERIMENTAL ARRANGEMENT

The experimental arrangement was the same as that described in an earlier paper.[3] The central fin, wrapped with 30 layers of MLI, was refrigerated to 4.2 K by liquid helium through a thermosiphon tube from the boiloff vessel, which was guarded by another liquid helium vessel. The outer box was maintained at 77 K by two thermosiphon tubes from a liquid nitrogen vessel. The accuracy of the wet test meter used for the helium gas boiloff is ±0.2%. The correction factor to convert the boiloff data to evaporation rates is 1.154. The thermocouples to measure the temperature distribution in the MLI blanket were Chromel/gold 0.07% iron and were installed in the same way as before.[2]

Fourteen slots, 254 mm long by 4 mm wide, were cut in the MLI blanket as shown in Figure 1. The patch material was 1000 angstrom double aluminized flat 6.35-μm Mylar.

EXPERIIMENTAL RESULTS

Effect of Slots on Heat Load

The heat load from the 77 K copper box to the 4.2 K black painted fin (area A = 2.24 m^2) through a 30-layer MLI blanket without cracks, Q_O, was 29.9 mW and the corresponding heat flux, Q'_O (Q_O/A) was 13.2 mW/m^2. The total heat load measured with slots in the MLI Q_c, was 32.42 mW. The heat load through slots

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defined as $Q_S = Q_C - Q_O$ was 2.52 mw. Since total area of the slots A_S was 0.014 mm^2, the heat flux through the slots Q'_S defined as Q_S/A_S was 180 mW/m^2. The heat flux through slots was therefore about 14 times that through a MLI blanket without slots ($Q'_S/Q'_O = 14$).

Patch Covering Techniques

To quantitatively verify the patch covering technique at the lower temperatures, the slots on layers 15, 20, 25 and 30 were covered with patches. The measured heat load was 30.3 mW, which is approximately equal to the original heat load through the MLI blanket without slots.

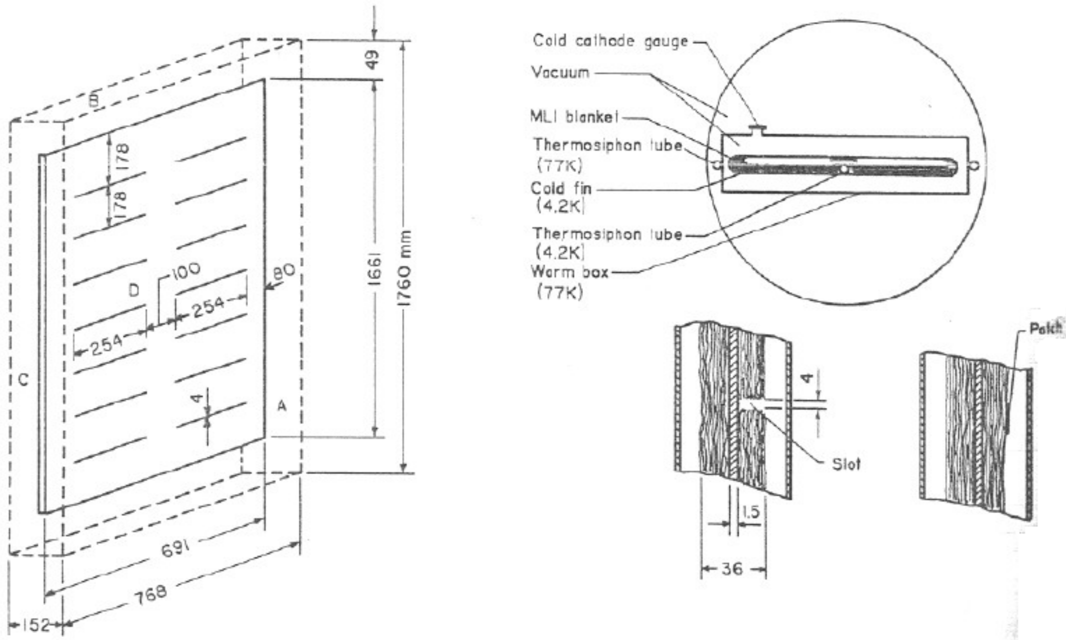

Fig.1. Schematic diagram of the cracks in the MLI blanket between 77 and 4.2 K.

Temperature Distribution and Thermal Conductivity

Figure 2 shows the temperature distribution in the 30-layer MLI blanket at a vacuum pressure of 5×10^{-8} torr for three different arrangements: (1) without slots, (2) with slots, and (3) with patches covering the slots on layers 15, 20, 25 and 30. Figure 3 gives the equivalent thermal conductivity of the slots, defined as $Q_S \cdot \triangle N/A_S \triangle T_N$, where $\triangle T_N/\triangle N$ is the local temperature gradient. It can be seen that the thermal conductivity in either the inner or outer portions of the MLI blanket is less than that observed in layers 12 to 22. The maximum conductivity of the slots is more than one order of magnitude greater than the conductivity of the blanket without slots. The values with patches covering the slots are about the same as without slots over the entire temperature range. Figure 4 shows the equivalent thermal conductivity as a function of temperature in a MLI blanket.

Temperature Difference Between Outer Layer and Warm Box

The earlier experiments,[2] from room temperature to 77 K, showed that the temperature difference between the outermost layer and the warm box was less than 2 K. However, the 77 to 4.2 K data showed a temperature difference of about 7 K.

CALCULATION OF HEAT LOAD THROUGH CRACKS

The heat load from the 77 K box to the 4.2 K surface through cracks can be calculated by means of the enhanced black cavity model,[6] The following calculation shows how the model may be used.

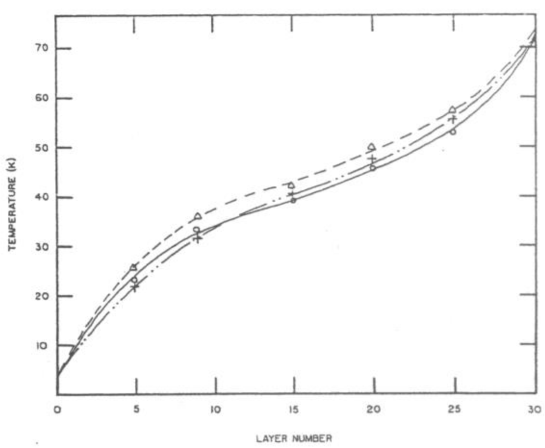

Fig.2. Temperature distribution in MLI blanket at a vacuum pressure ~ 5×10^{-8} torr.○,without slots; △, with slots; +,with patches covering slots.

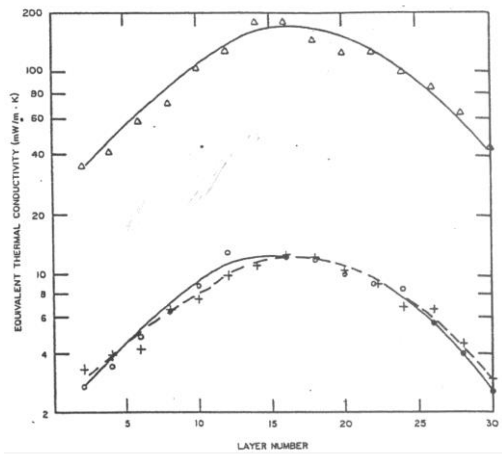

Fig.3. Equivalent thermal conductivity as a function of depth in a MLI blanket. ○,without slots; △, with slots; +,with patches covering slots.

$$Q_S = \eta\sum_{i=1}^{n}\varepsilon_2\alpha T_2^4\left[S_i(F_{S_i-A} + F_{S_i-B} + F_{S_i-C})\right] \tag{1}$$

where n is the number of slots, η is the total enhancement factor; α is the Stefan-Boltzman constant 5.67×10^{-8} Wm^{-2} K^{-4} ; ε_2 is the emissivity of the warm box; T_2 is the temperature of warm box; S_i is the area of slot i. F_{S_i-A}, F_{S_i-B}, and F_{S_i-C} are the view factors from slot i to the warm walls A, B, and C, shown in Fig. 1.

Evaluating the quantity inside the brackets of Eq. (1) is usually difficult. A general series approximation can be found in Ref. 5. A solution for the geometry of Fig. 1 was calculated earlier and are as follows: $S(F_{S-A})$ = 0.013, $S(F_{S-2B})$ = 0.000042, and $S(F_{S-2C})$=0.0014. Each slot is viewed by both end and both side plates, but by only one front plate. The total enhancement factor can be determined by a combination of theoretical calculations and experimental results. For our apparatus, η was 3.8.[6]

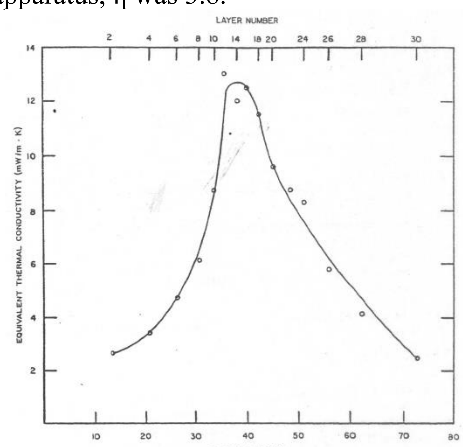

Fig.4. Equivalent thermal conductivity as a function of temperature in a MLI blanket.

The total heat load through the slots, using Eq. (1) and the above approximation

$$Q_S = 30.7\times10^{-10}\varepsilon_2 T_2^4 \tag{2}$$

Assuming ε_2 = 0.03, the total heat load through the slots from the 77 K warm box to the 4.2 K surface is 3.04 mW. If ε_2= 0.02, then Q_S = 2.1 mW; the dependence of Q_S on the emissivity is $100\varepsilon_2$.

DISCUSSION AND CONCLUSION

From the above experiments, it is obvious that the theory and the technique developed to reduce the effects of cracks in a MLI system between room temperature and 77 K is useful for the 77 to 4.2 K temperature region.

The basic conclusions are:

1. The heat flux through cracks in a 30-layer MLI blanket between 77 K and 4.2 K is 180 mW/m^2, which is fourteen times the flux through the same MLI blanket without cracks.
2. Compared to the case of a MLI blanket between room temperature and 77 K, where the heat flux through cracks is nearly two hundred times that through the blanket, the effect from 77 K to 4.2 K is less. One of the reasons is that the heat transfer in a MLI system between room temperature and 77 K at very low vacuum pressure is primarily by radiation, while solid conduction plays a more important role between 77 K and 4.2 K.
3. The patch covering technique optimised for the temperature region between room temperature and 77 K also works very well from 77 K to 4.2 K. The experimental data shows that the use of just four patches uniformly spaced in the warm half of the blanket restored the thermal performance of the blanket to that without cracks. On the other hand, the careless installation of patches might cause a serious increase in heat load due to additional solid conduction.
4. The temperature distributions in a MLI blanket between 77 K and 4.2 K are quite different from those at higher temperatures. The equivalent thermal conductivity calculated from the temperature distribution is interesting: It has a broad maximum near the center of the blanket. This is in contrast to a MLI blanket between room temperature and 77 K, where the equivalent thermal conductivity always increases with increasing temperature.
5. The temperature difference between the last layer and the warm box is ~7 K for a 30-layer blanket between 77 K and 4.2 K. This is larger than the 2-K difference in the room temperature to 77 K case. Therefore, contact of the last layer to the warm box will cause a more serious heat load increase from 77 to 4.2 K than from room temperature to77 K.
6. The enhanced black cavity model is also satisfactory for the 77 to 4.2 K temperature region.

REFERENCES

[1] Q.S. Shu, R.W. Fast, and H.L. Hart, Theory and technique of reducing the effect of cracks in multilayer insulation from room temperature to 77 K, in: 'Advances in Cryogenic Engineering,' VoL 33, Plenum Press, New York.

[2] Q.S. Shu, R.W. Fast, and H.L. Hart, Heat flux from 277 to 77 K through a few layers of multilayer insulation, Cryogenics 26:671 (1986).

[3] E.M.W. Leung et al., Techniques for reducing radiation heat transfer between 77 and 4.2 K, in: 'Advances in Cryogenic Engineering,' Vol. 25, Plenum Press, New York, p. 489.

[4] Q.S. Shu, R.W. Fast, and H.L. Hart, Systematic study to reduce the effects of cracks multilayer insulation. Part 2: experimental results, Cryogenics 27:298 (1987).

[5] R. Siegel, "Thermal Radiation Heat Transfer, " NASA Report SP-164, U.S. Governmeat Printing Office, Washington (1971).

[6] Q.S. Shu, Systematic study to reduce the effects of cracks in multilayer insulation. Part 1: theoretical model, Cryogenics 27:249 (1987).