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MEASUREMENT ON DIFFERENT MLI SYSTEMS BETWEEN 77 K AND 4 K AND THEIR APPLICATION IN CRYOGENIC ENGINEERING

V. Benda, D. Bozzini, G. Riddone and G. Vandoni

Abstract

Precise thermal measurements were done on different types of large surface MLI samples under various boundary conditions. The measurements were focused on the use of MLI for large industrial plants considering quick and simple installation. The results of the measurements aim at optimising MLI parameters, which control the thermal behaviour. Practical recommendations of MLI materials and their installation are given.

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ABSTRACT

Precise thermal measurements were done on different types of large surface MLI samples under various boundary conditions. The measurements were focused on the use of MLI for large industrial plants considering quick and simple installation. The results of the measurements aim at optimising MLI parameters, which control the thermal behaviour. Practical recommendations of MLI materials and their installation are given.

INTRODUCTION

Multilayer insulation (MLI) has been used in cryogenic application for more than 40 years, mainly to operate between 300 K and 77 K or lower. In this region MLI is well investigated and many results and recommendations are found in literature [1,2]. Less effort has been done to investigate MLI between 77 K and 4 K or below, so investigations in this temperature range were launched at CERN in the framework of the LHC project.
The heat flow through MLI is shared between radiation, conduction and convection in a way depending on the temperature range [3]. Under good vacuum conditions, while between 300 K and 77 K approximately 9/10 of the total heat flux are due to radiation, between 77 K and 4 K radiation accounts for only 1/10 of the heat flux, the main fraction being due to solid conduction of the MLI itself. The conductivity depends on the spacer material, on its configuration and on the compression of the blanket. The ultimate heat flow will result from a trade-off between the optimisation of the MLI elements, the installation methods and the cost of industrial solutions applicable on a large scale.
In all the measurements presented here, the MLI blanket contained 10 reflectors. Vacuum conditions vary between 10^{-5} Pa and 10^{-1} Pa. Two different laboratory set-ups are used.

1. RESULTS

The first measurements we present are done on a cylindrical test cryostat with vertical orientation [4]. The MLI sample, of total surface area ~3 m^2, is installed in a vacuum chamber around a vertical cylinder maintained at 4.2 K by saturated liquid helium and surrounded by a warm cylinder maintained at 78 K by boiling liquid nitrogen. The heat flux is measured by boil-off. Results are summarised in Table 1 and Figure 1. We measured different reflector (flat or crinkled) and spacer types, bound to reduce the transverse conductivity of the blanket, and studied also the effect of a contamination of the outer layer by concrete dust.

The radiative heat flow between two surfaces depends on the boundary temperatures and emissivities as well as the view factor. To get rid of this parameter, a second test set-up of horizontal flat plate geometry has been built [5]. The apparatus consists of a warm-boundary and a cold-boundary plate connected to a heatmeter, onto which the MLI sample is placed. Both plates are surrounded by a thermal shield and placed in a vacuum chamber.
Whereas in the vertical cryostat we could measure installation compression getting rid of self-compression, in the horizontal set-up we only have self-compression, without mounting compression.

Table 1: Heat flux measured in the cylindrical, vertical axis cryostat, as a function of helium residual pressure.

No	Type	Installation/ closing	Spacers	Heat flux [W/m^2] 10^{-5} Pa	Heat flux [W/m^2] 10^{-2} Pa
1	DAMS1	blanket/tape	SS	0.040	0.160
2	DAMcS1	blanket/tape	VS	0.022	0.082
3	DAMS2	wrapped	DS	0.037	0.160
4	DAMS2*	wrapped	DS	0.049	0.250
5	SAMc	blanket/tape	none	0.032	0.190
6	AlS1	blanket/tape	SS	0.100	0.210
8	DAMVS1	blanket/ Velcro®	VS	0.063	0.150
9	DAMcVS1	blanket/ Velcro®	VS	0.050	0.110
10	DAMVS1	blanket/ Velcro®	DS	0.055	0.130

DAM Double aluminised Mylar,
SAM Simple aluminised Mylar,
c Crinkled reflector
S1 Fibreglass paper spacer
S2 Tulle net spacer,
V Velcro® fastener,
* External layer polluted with concrete powder
SS Single spacer
DS Double number of spacers
VS Number of spacers variable from layer to layer: cold side, 3 spacers between 2 reflectors, warm side, 1 spacer between reflectors, for a total of 15 spacers.

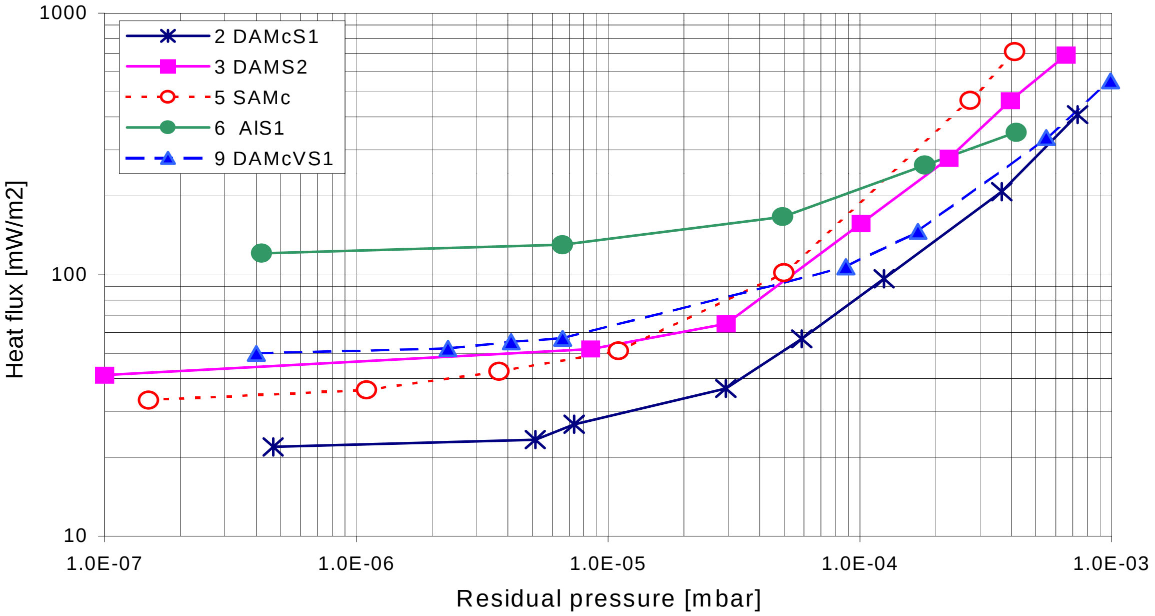

Figure 1: Heat flux measured in the cylindrical, vertical axis cryostat, as a function of helium residual pressure.

In the horizontal cryostat, we measured samples with different configurations of a Velcro®[1] closing, and compared them with the same samples without Velcro®. The results at 77 K warm boundary are given in Table 2. For better comparison with Table 1, we translated the bare results into the cylindrical geometry of the vertical cryostat, with copper (emissivity 0.07 at 77 K) as the emitter surface. Here, the vacuum is kept below 10^{-5} Pa.

2. DISCUSSION

Previous results showed that at good vacuum, the heat flux is nearly the same if the cold surface is protected with MLI or with one layer of Al foil [2,4]. The utility of multiple layers appears at poor vacuum, where the larger the number of layers the better the insulation [3]. A multi-layer blanket made of 0.05 mm thick Al reflectors with conventional spacers, yields a higher heat flux than with aluminised Mylar™ [2] reflectors ([6] and curve 6). The reason is the large longitudinal conductivity of the Al foil, which enhances the effect of thermal bridges, as well as a larger transverse conductivity resulting from the plasticity of the foil and the consequent number of point contacts.

Crinkled MLI always lowers the heat flux. Crinkling reduces the number of point contacts, and hence the transverse conductance. In a cylindrical geometry crinkled reflectors compensate for the length difference between layers, the spacers taking up the length difference by deformation. The same advantage is obtained with a reflector in one piece, wrapped in 10 layers (Table 1, 3-4), though this is not compatible with all geometries. A thicker spacer material (S1 versus S2) can reduce the heat flux at low residual pressure.

Crinkled SAM without spacers is cheap and performs well from a thermal point of view. Crinkled reflectors, alternated with a number of spacers variable from layer to layer, yield the lowest heat flux over the whole pressure range (as low as 22 mW/m^2 at 10^{-5} Pa).

Table 2: Heat flux in the flat-plate geometry, at 77 K warm boundary, acronyms explained in table 1

No	Type	Spacers	Installation	Heat flux [W/m^2]
1	DAMS2	SS	1 circular whole blanket	0.030
2	DAMS2	DS	1 circular whole blanket	0.027
3	DAMS1	DS	1 circular whole blanket	0.026
4	DAMS2	SS	2 semi-circular blankets connected with Velcro®, overlapping junction	0.050
5	DAMS2	SS	2 semi-circular blankets connected with Velcro®, edge-to-edge junction	0.042
6	DAMS2	SS	2 semi-circular blankets connected with Velcro®, edge-to-edge, junction covered with aluminized Mylar	0.038
7	DAMS2	DS	2 semi-circular blankets connected with Velcro®, overlapping junction	0.063

A Velcro® closing always increases the heat loads, particularly in good vacuum, where the heat flux exceeds 50 mW/m^2. An edge-to-edge junction is to be preferred with respect to overlapping the blanket edges, which thermally bridges the warmest layer to the coldest one. The radiation leak through the slit onto the Velcro® is effectively screened by one stripe of aluminised Mylar. The measurements also show the effect of local compression due to the stitching of the Velcro® to the blankets (Table 2, samples 4-7), an effect which is further increased by a higher number of spacers with the same tension of the stitches (Table 2, samples 4 and 7). In the absence of Velcro®, doubling the number of spacers has given a barely sizeable effect in horizontal geometry.

Experience shows that a correct installation of the blankets is as important as the choice of the materials, the installation accounting for a spread in the heat flux by a factor 2. One advantage of using Velcro® in industrial applications is that the dependence on the ability of the installator is reduced, allowing for quicker installation and hence reducing the costs.

A contamination by concrete dust (present in installation areas) of the outer layer affects the heat flux, but does not result in a large effect if the spacers are of good quality, since it only increases the emissivity of the outer layer and hence only adds to the less consequential effect of radiation with respect to the more determinant effect of solid conduction.

3. THERMAL CONTRACTION OF MLI AND VELCRO®

Industrial applications need simpler solutions than hand-stitching or adhesive tape fastening. The use of Velcro® fastener stitched to the blanket requires some prudence. Results on two measured samples, presented in Table 3, show that the thermal contraction can vary from one sample to another. The differential thermal contraction between MLI and the type of Velcro® must be minimised to avoid tearing or deforming the blanket.

Table 3: Thermal contraction of Velcro and MLI for 2 different samples between 300 K and 77 K

Sample 1		Sample 2	
Velcro® [mm/m]	MLI [mm/m]	Velcro® [mm/m]	MLI [mm/m]
2.4 +/-0.5	2.4 +/-0.5	1.3 +/-0.5	2.8 +/-0.5

CONCLUSIONS

When choosing a MLI to work between 77 K and 4 K, the choice should be made on a case-by-case basis, depending on the operational vacuum conditions, the geometry and orientation, the ease of installation and the quantity.

Light materials reduce the self-compression in a horizontal set-up. Crinkled reflectors also reduce the transverse conductivity, and have dimensional advantages in a cylindrical system. Varying the number of spacers from layer to layer permits to put more spacers where needed and improves the insulation without making the blanket uselessly heavy.

The installation should ensure a low blanket density. Velcro®, with respect to adhesive tape or hand stitching, helps in making the installation more reproducible, and allows faster installation, but should be applied with caution, limiting its length, evaluating thermal contraction, and closing slits at the junction by a stripe of aluminised Mylar™.

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[1] Velcro®, is the Registered Trade Mark of Velcro Industries B.V

[2] Mylar™, is a trademark of DuPont de Nemours