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*Large Hadron Collider Project*

**LHC Project Report 220**

**THERMAL PERFORMANCE OF INSULATING CRYOGENIC PIN SPACERS**

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**Abstract**

Following the proposal to introduce an actively cooled radiation screen (5-10 K) for the LHC machine, the design of the LHC cryostat foresees the need for spacers between the cold mass and the radiation screen. The thermal impedance of the chosen material should be very high and the shape selected to withstand the contact stress due to the displacements induced by the cool-down and warm-up transient.

A cryogenic experiment dedicated to studying the thermal behaviour of several proposed spacers was performed at the cryogenics laboratory of CERN before choosing the one to be used for further investigation on the LHC full-scale Cryostat Thermal Model [1] [2].

This paper describes a quantitative and qualitative analysis leading to the choice of the spacer.

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## 1 INTRODUCTION

The refrigeration system of the LHC machine has to provide stable cryogenic conditions for operating long strings of superconducting magnets in superfluid Helium. To reduce operation costs due to residual static heat in-leaks, the proposed LHC cryostat insulates the magnets from ambient by using two actively cooled aluminium shields at 50-75 K and 5-10K, respectively. Spacers are required to avoid thermal short-circuit between the inner shield and the cold mass. The main requirement for these spacers is high thermal impedance.

After a pre-selection based on physical properties, several possible spacer materials have been retained for further theoretical and experimental thermal evaluation. The best performing spacers, made of Carbon-Carbon composite, have been used to equip a full-scale Cryostat Thermal Model, which has been tested in February/ March 1998 (Figure 1).

## 2 SPACER FUNCTIONAL SPECIFICATION

The inner 5-10 K shield of the LHC 15-m cryostat [3] is composed of an extruded lower tray welded to 2.5-mm thick aluminium sheets (upper shells). This assembly, termed the radiation screen, is supported by the three magnet supports. A nominal radial gap of about 6 mm. exists between the radiation screen and the cold mass, however due to the intrinsic flexibility of the top shells, unwanted contact may occur. The pin spacers ensure mechanical stability of the screen through periodic contact with the cold mass whilst minimising the heat transfer by solid conduction.

To minimise contact area whilst retaining sufficient mechanical strength, the pin spacer has a hemispherical head and is axially fixed the radiation screen.

Under the most rapid cool-down conditions, the highest possible force on a single spacer is estimated at 300 N (Figure 2). The contact surface between a spacer and the radiation screen must be large enough to support the screen without deforming it plastically under the effect of such a force.

Every upper shell needs to be supported by 6 spacers (Figure 1). They are located in two sets of three, each set located in a plane at 150 mm from each extremity of the shell and circumferentially spaced 60 degrees apart around the cold mass. The two main properties required for an optimal material are a low thermal conductivity and a high Young's modulus at low temperature. Under nominal conditions, the spacers will be submitted to a negligible radiation dose ( $< 3$  Gy/yr).

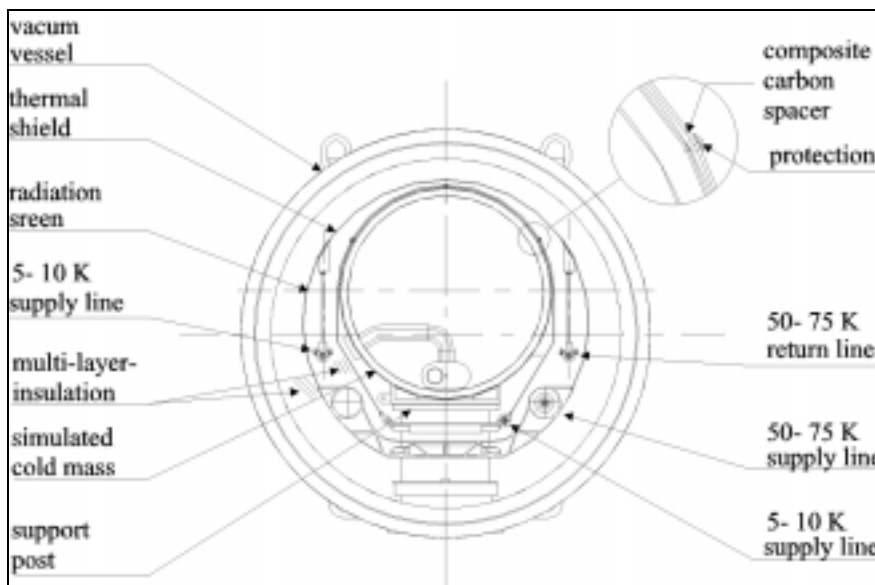


Figure 1: Location of the insulating cryogenic pin spacers on the Cryostat Thermal Model

### 3 THEORETICAL THERMAL ANALYSIS

The simplified geometry for the numerical analysis is displayed in Figure 2 in axial symmetry. The contact area of the spacer to the cold mass is circular, with radius  $R_c$  depending on the following expression [4]:

$$R_c = 0.9086 \sqrt[3]{P.R. \left[ \frac{(1-\mu_1^2)}{E_1} + \frac{(1-\mu_2^2)}{E_2} \right]}$$

$R$  is the nominal radius of the pin spacer head,  $\mu_1$  and  $\mu_2$  are the Poisson's ratio and  $E_1$  and  $E_2$  the Young modulus for the cold mass and the spacer, respectively. Contact forces  $P$  of 400 N, 300 N, 200 N and 100 N have been considered.

The characteristics of the pre-selected materials: Carbon-carbon composite, Glass fiber/ Epoxy (ME711), Composite carbon fiber (Carbon/ Vinylester) and Polyethylene (HDPE) are presented in Table 1.

Since the Poisson's ratio  $\mu$  for these materials decreases slightly with temperature, an approximate value at 4 K of 0.3 has been used.

The temperature of the surface contact with the cold mass ( $T_1$ ) is fixed at 1.9 K whereas the boundary temperature of the radiation screen ( $T_2$ ) varies from 5 K to 40 K.

In order to simulate the worst case the surface contact resistance is taken as zero. Radiation and residual gas conduction are considered to be negligible and the heat transfer process is governed by Fourier's law.

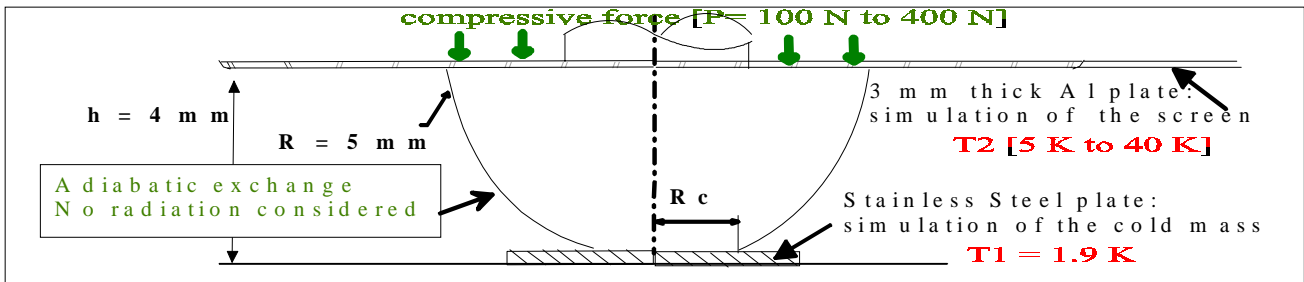


Figure 2: General definition of the problem.

Finite element analysis allows the temperature distribution to be obtained. The heat flux is then calculated from this temperature distribution.

The thermal conductivity of the carbon-carbon material depends on the temperature [5] according to the law  $\lambda(T) = 8.4E-4 T$ . The thermal analysis, consequently non-linear, of this material requires an iterative Newton-Raphson type solution. For the other materials basic linear analysis is performed using ANSYS®.

### 4 EXPERIMENT

Pin spacer samples in four materials have been manufactured and then tested in a HeII cryostat at the CERN cryogenic laboratory.

The heat flux through the pin spacer is measured with a precision of  $\pm 10\%$  (Figure 3) by a calibrated thermal impedance termed a heat-meter [6]. The pin spacer is mounted on an aluminium plate whose temperature can be varied between 10 K and 40 K.

The force on the aluminium plate can be increased from 100 N to 400 N to bring the pin spacer into contact with a stainless steel plate, simulating the cold mass surface and mounted on the heat-meter.

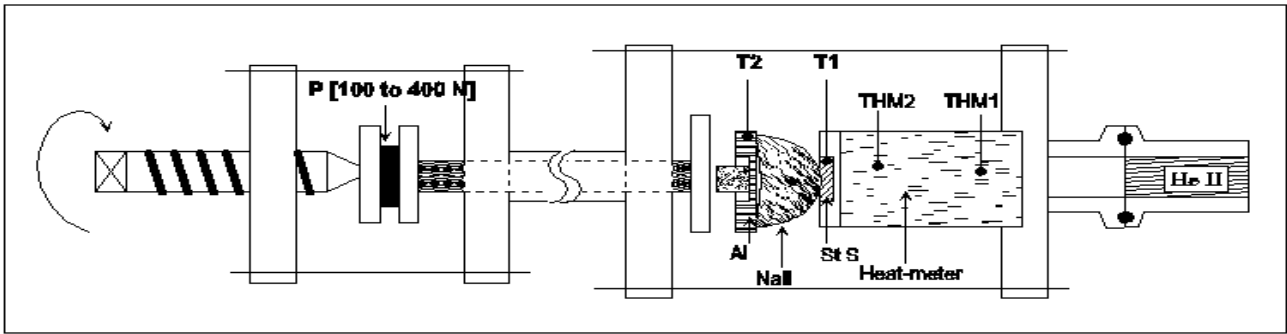


Figure 3: Schematic view of the experimental set-up for heat load measurements. The subscript HM indicates heat-meter instrumentation; T1 corresponds to the cold mass, T2 to the radiation shield temperature.

## 5 HEAT FLUX THROUGH PIN SPACERS

Table 1 summarises the properties of the pre-selected materials [7], [8], [9] and their performance. Figure 4 compares the thermal performance of the materials under varying radiation screen temperature (T2).

The best thermal behaviour at low temperature is observed for the carbon/carbon spacer.

Materials	1: Carbon/ Carbon	2: Glass/ Epoxy	3: Carbon/ Vinylester	4: Polyethylene
$\rho$ [g/cm <sup>3</sup> ]	1.30-1.80	1.85	1.50 – 1.65	0.45 E-3
E @ 4 K [GPa]	300	40	220	9
$\lambda$ @ 4 K [mW/mK]	3.36	~70	30	12.7
Rc for P=300 N [mm]	0.202	0.312		0.491
Numerical results (a)	0.042	0.247	0.264	0.095
Measurements	0.037	0.101	x	x

Table 1: Characteristics and performances of the materials tested.

Under typical radiation screen operating conditions (a: where T2=10 K and P=100 N), the heat flux per pin spacer has been measured at 0.037 mW for material 1 and 0.101mW for material 2. If T2= 15 K and P= 200 N, the measurements for materials 2, 3 and 4 are 0.655 mW, 1.93 mW and 0.644 mW, respectively. According to the numerical approach the thermal contact is important to consider in order to model the behaviour of the spacer.

## 6 CONCLUSION

The analytical estimates of heat flux by conduction through pin spacers have been confirmed by experimental measurements. Carbon-carbon pin spacers have been used effectively in the CTM, where the forty-two spacers installed conduct a total 1.6 mW of heat from the radiation screen to the cold mass, compared to 164 mW with a previous type of spacer [10]. Over the range of temperature differences and contact forces investigated, the carbon-carbon pin spacer conducts between 2.5 and 5 times less heat than the polyethylene equivalent but costs approximately 3 times more. The use of carbon-carbon pin spacers in LHC will depend strongly on a cost competitive large scale manufacturing method being found.

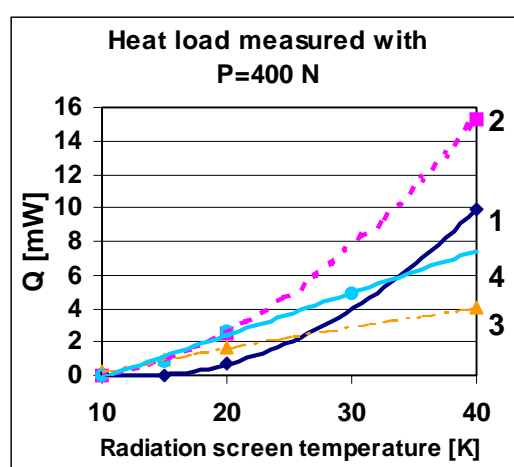
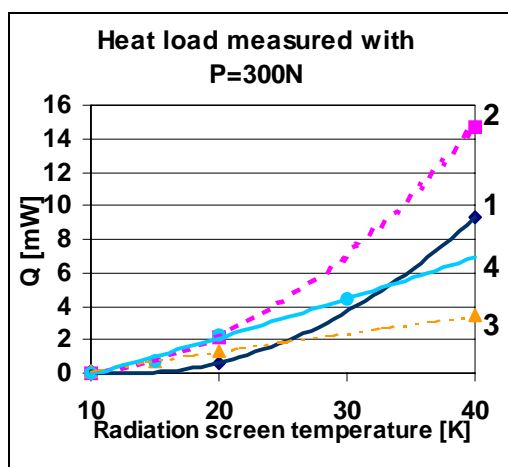
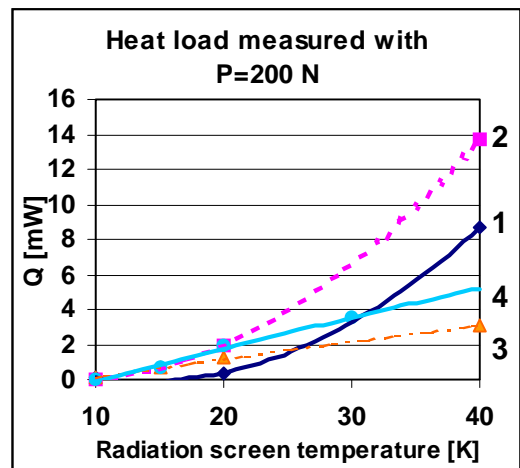
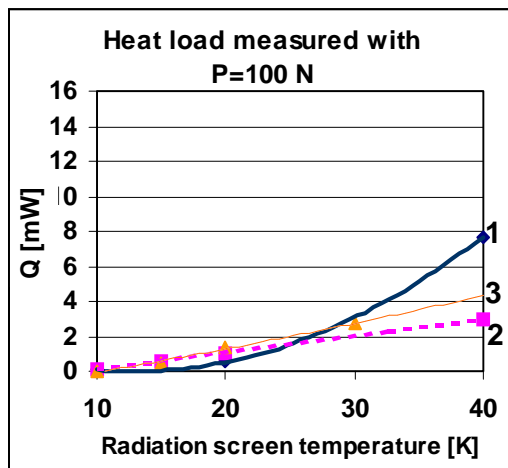


Figure 4: Heat flux through spacers, versus the radiation screen temperature.  
 Q1, Q2, Q3 and Q4 are the heat fluxes under the typical LHC condition: T1=1.9 K, T2=10 K, P= 100 N.  
 Q\* has been measured with the same force but for T2= 15 K

## 7 REFERENCES

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