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THERMAL MEASUREMENTS ON THE LHC COLLIMATOR MODEL

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Abstract

One of the most critical design issues in the LHC collimators is the clamping of the graphite (or carbon-carbon composite) particle absorber onto the copper cooling circuit. The thermal impedance at their interface depends on several material parameters and although theoretical models exist in the literature, an experimental assessment was deemed necessary in the light of the criticality of these components. In this note the experimental setup and the measured data are briefly presented.

1 EXPERIMENTAL SET-UP

One of the most critical design issues in the LHC collimators is the clamping of the graphite (or carbon-carbon composite) particle absorber ("jaw") onto the copper cooling circuit. The thermal impedance at their interface depends on several material parameters such as the roughness, the elastic modulus and the contact pressure of the two materials and although theoretical models exist in the literature [1], an experimental assessment was deemed necessary in the light of the importance of these components. For this purpose a test bench has been set-up (Figures 1 and 2). Its design is similar, but not equal to the final collimator design that has evolved in the following time, in particular in the number of cooling channels. The set-up consists of one real-size C-C jaw (AC150 by Tatsuno) clamped onto its cooling circuit and mounted vertically inside a vacuum chamber. The clamping pressure can be adjusted by changing the compression of the stainless steel springs that act on the lateral clamps, knowing from datasheets their elastic constant. A large heat flux can be deposited on the C-C jaw surface with a set of two resistors positioned along its axis, having a total length of about 1m and capable of dissipating a total power up to about 4 kW. The resistors are pressed against the jaw through CuBe steel springs, but the contact pressure is not estimated precisely. However the heat flux has no other route than going into the C-C, except for the small mechanical pieces that hold the resistors in place and for heat that may be radiated away. A reflecting copper screen helps in reducing the latter, will be anyway shown to be negligible. The former route for the heat flux may indeed subtract some power, but this will experimentally be shown to be acceptable. The two cooling circuits are fed with chilled water and floating meters are used for the measurement of the liquid flow.

The C-C jaw (in three positions), the copper cooling plate, the stainless steel clamps and the resistors are all instrumented with thermocouples of type E for temperature measurement (Figure 3), which are located at about 2/3 height of the C-C jaw. The input and output of the cooling water circuit are also monitored, and all the thermocouples are connected to the same patch panel where the transition to standard copper conductors is done. The measurement is accurate if the temperature difference of a thermocouple from a reference one is taken, such as the one measuring input cooling water. The thermocouple signals are acquired with a computer system every 10 seconds together with the values of the applied power and of the vacuum gauges.

2 EXPERIMENTAL RESULTS

Several runs have been performed with different clamping pressures, by adjusting the springs compression measured against reference markings. The clamping pressures of 2.4, 3.6 and 6 bar have been tested. For each pressure level, the heating power has been varied widely, most often in increasing steps up to the maximum of 4 kW. At the pressure of 6 bar and for a heating power of 2 kW the change of water flow from the standard 5 lt/min (per cooling channel) down to 3 lt/min has also been studied. The base vacuum before the experiments was in the 10^{-7} mbar range, and when heating at the maximum power the pressure never increased beyond the 10^{-4} mbar range, thus ensuring that heat conduction by the gas is negligible.

An example of the measured temperatures is reported in Figure 3, which illustrates also the position of the different thermocouples. From this figure one can remark that the temperature of the stainless steel clamp is higher that that of graphite, meaning that some heat is flowing along the path resistors-clamp-C-C. However, although this affects the temperature distribution inside the C-C jaw thus complicating its comparison with numerical simulations, it does not hinder the assumption that the heat produced by the resistors flows mainly across the C-C / copper cooling plate interface. Besides a temperature of about 200 ºC of the copper resistors (as in this particular case) means a power of less than 5 W lost through radiation, which is negligible compared to that flowing by conduction.

The temperature gradient across the C-C / copper cooling plate interface was the quantity that needed the more careful experimental check. This was characterised using the measurements from the temperature probes located in the copper plate and in the C-C jaw closest to the plate. First of all, it has been demonstrated that the temperature gradient measured is perfectly linear with the applied power, for all the different values of clamping pressure. From the values of the temperature gradient and of the contact area it is possible to calculate the thermal conductance coefficient as a function of the contact pressure, which is reported in Figure 4 with the relevant error bars. The data are fitted with the form $K=a*p^b$ where a and b depend according to [1] to several material parameters, b being of the order of 0.9. It should be underlined that the heat flow across the interface is certainly not uniform, as is the temperature gradient which is only measured at its centre, thus the calculated K coefficient is only an indicative value. However the results obtained obey a law very similar to the theoretical expectations. This is a good indication of the validity of the design assumptions, and a reliable starting point for a more detailed finite element analysis of the collimator design using a pressure-dependent heat exchange coefficient based on experimental data. A final comment should go the thermal stabilisation time of the system that has been investigating by switching on the resistors at 2.5 kW, and which is of the order of 2 minutes for the C-C jaw as illustrated in Figure 5.

3 CONCLUSIONS

The measurements carried out on the collimator thermal test bench have been briefly summarised. These are in very good agreement with the calculated behaviour based on a literature model for the thermal impedance at the C-C / copper interface, and are a solid base for the fine-tuning of the above model. All the measurement data files are available under the links \\cern.ch\dfs\Divisions\EST\Groups\SM\ThinFilms\DataFiles\StandardSystem\Collimator\ and \\cern.ch\dfs\users\s\scala\Public\ .

ACKNOWLEDGEMENTS

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REFERENCES

[1] E. Marotta, S. Mazzuca, J. Norley Electronics Cooling August 2002

FIGURES

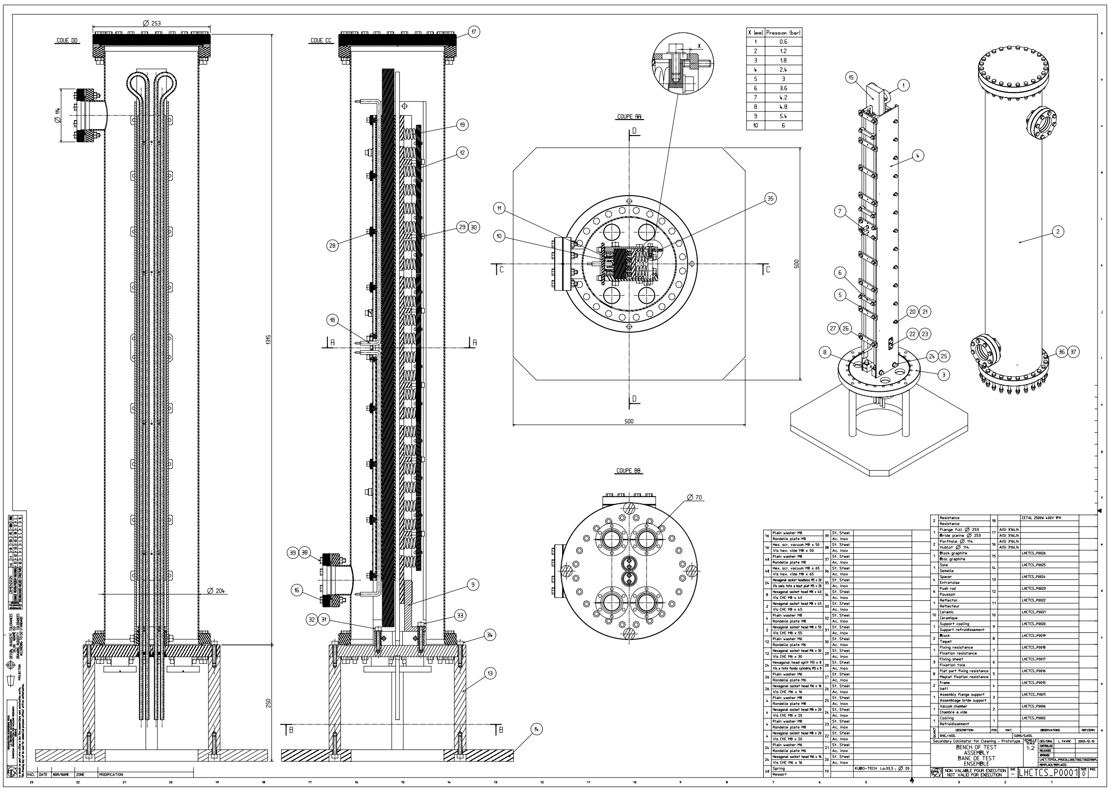

Figure 1: Drawing of the test bench

Figure 2: Picture of the test bench. The resistors are in the front.

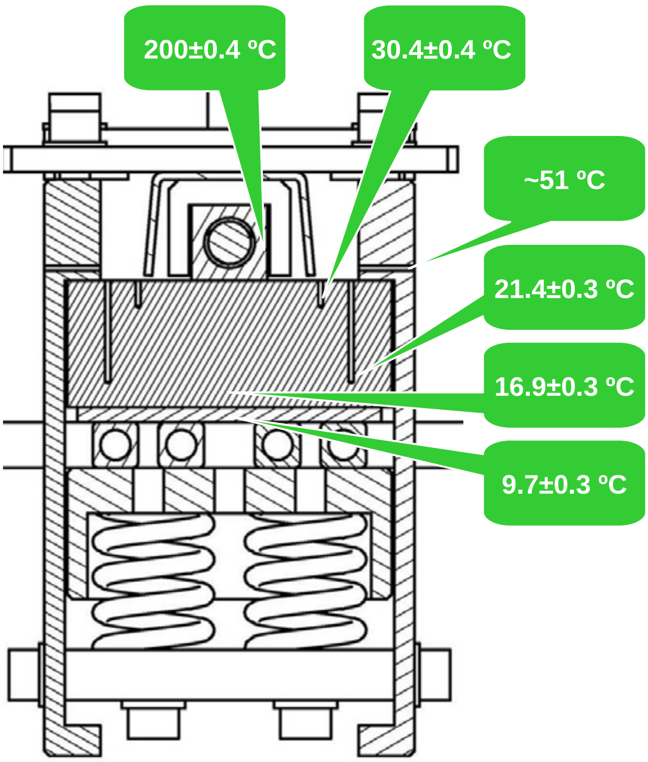

Figure 3: Cross-section of the test bench. The resistors are on the top of the C-C block, which is clamped onto the cooling circuit by the springs. The position of the temperature sensors is indicated by the arrows, and the temperature increase from the reference of the cooling water is reported for the case 4 kW – 6 bars – 2x5 lt/min of water in the cooling channels.

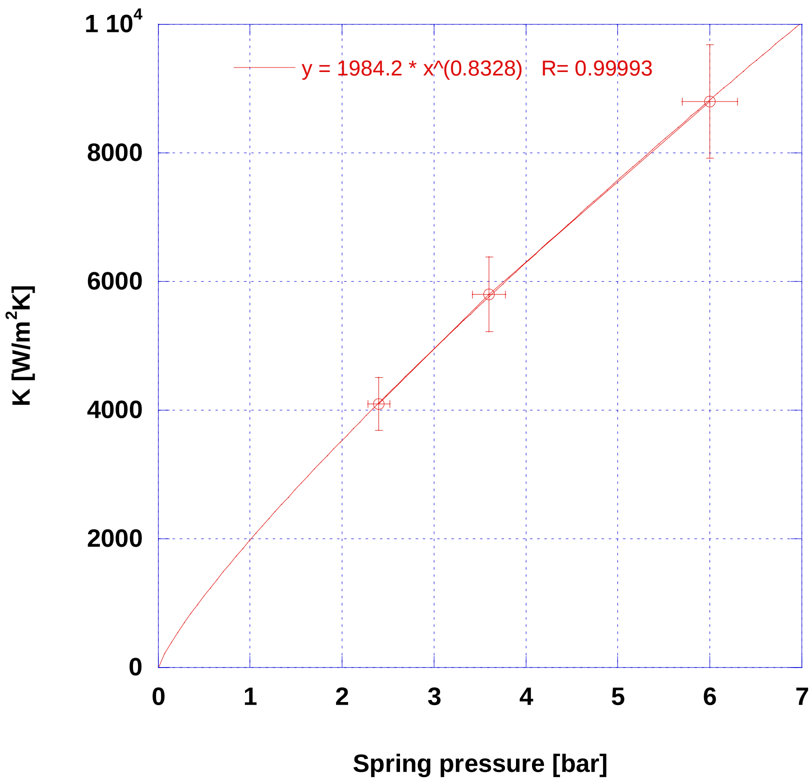

Figure 4: Thermal conductance as a function of the applied pressure. The data are fitted with the formula $K=a*p^b$, the exponent b having a value of 0.833 compared to the theoretically expected value of 0.935.

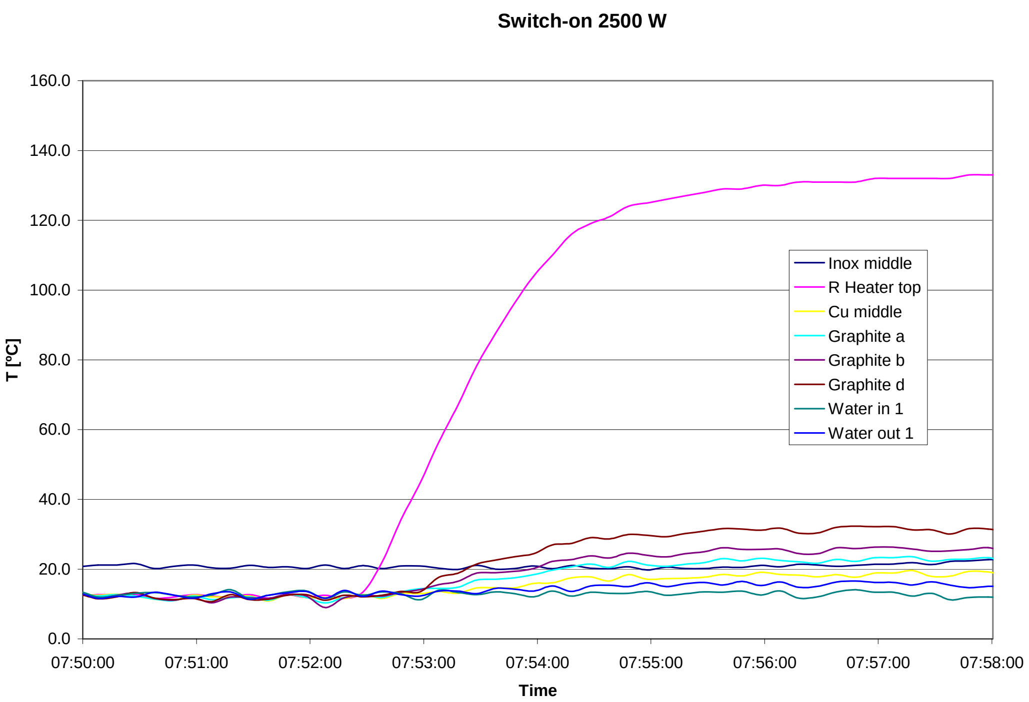

Figure 5: Temperature evolution at switch-on of the resistors. The stabilisation time is less than 2 minutes, except for the resistors themselves.