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Test of the per-fluorocarbon cooling system with the Tile hadron calorimeter of ATLAS

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Abstract

The Leakless Cooling System (LCS) working with the per-fluorocarbon has been tested in real conditions with the central barrel module 0 of the TILECAL hadron calorimeter of the ATLAS detector. The results obtained have shown similar performances with respect to the water cooling system installed since 1997 in the test beam. Nevertheless some small problems of stability should be cured for a good working in the ATLAS conditions.

1 Introduction

The TILECAL hadron calorimeter of the ATLAS experiment is designed with the front-end electronics inside the girder of each module, which is located at the external radius of the calorimeter. The electronics boards are fixed on a drawer supporting the photomultipliers used to collect the light coming from the tiles, via optical fibres [1]. In this context, the power consumption, per super-drawer, is expected to be around 200 Watts [2]. Cooling is necessary to evacuate the heat for good working of the electronics, namely at a temperature less than 40^0C. The sensitivity of the photomultiplier is such that a temperature stability better than 2.5^0C is required. Furthermore, to avoid dew point problems, which can create short-circuits on the electronics board, the temperature must be greater than 18^0C; and the relative humidity should be well controlled.

With these conditions, the cooling system should be designed by taking into account the previous requirements and by fitting the mechanical constraints [2]. The choice made for the TILECAL is a Leakless Cooling System (LCS) working under-pressure at the level of the calorimeter.

Since the 1997 test beam, a prototype of the LCS using the water has been successfully tested in real conditions with the central and extended (see Ref. [2]) barrel modules 0.

For safety reasons, a more volatile and non-conductive liquid would be preferable to water. The proposed liquid is the per-fluorocarbon (C_6F_{14}) which is compared in table 1 with the water in terms of thermodynamical properties [3]. From these properties, and specially from the heat capacity, it seems that a liquid flow four times greater is needed for the C_6F_{14} with respect to the H_2O to get the same evacuation of heat.
The disadvantage of the per-fluorocarbon is its high price: roughly 100 ChF/l with respect to 0.5 ChF/l for demineralized water.

Liquid	H_2O	C_6F_{14}
Density ($\mathrm{kg\,m^{-3}}$)	998	1688
Specific heat ($\mathrm{J\,kg^{-1}\,K^{-1}}$)	4182	1045
Thermal conductivity ($\mathrm{W\,m^{-1}\,K^{-1}}$)	0.600	0.058
Viscosity (cSt)	1.00	0.41
Saturated vapour pressure (Torr)	17.8	210

Table 1: Thermodynamical properties of the water (H_2O) and of the per-fluorocarbon (C_6F_{14}) at 20^0C.

In December 1998, a test of the LCS-C_6F_{14} has been done in real conditions with the central barrel module 0. The goal of this test was double:

- to study the performances of the per-fluorocarbon,
- to study the effect of each electronics board on the temperature in several parts of the girder.

2 Temperature measurement

The temperatures are measured with silicon probes read with a 12 bit ADC mounted on the high voltage distributor cards (HVOPTO). The accuracy of these probes is such that:

$$1\,LSB \approx 0.1^0\mathrm{C}\ .$$

The probes are located in several positions of the super-drawer containing the digitizer boards:

- in the frame of the internal drawer (probe called "drawer"),
- on the middle of the external HVOPTO card (probe called "HVOPTO"),
- in the PMT block number 36 which is equipped with an end-cap:
  - near the 3-in-1 board (probe called "3-in-1"),
  - near the photomultiplier (probe called "PMT").

3 Water system

To have a reference in the test of the per-fluorocarbon system, we also operated for 10 hours with the usual water system.

3.1 Presentation

The Leakless Cooling System working with water is designed, see Fig. 1 [2], with:

- a lower unit (below the TILECAL module) containing the tank of water stabilised at 18^0C and the pump for the circulation,
- an upper unit (above the TILECAL module) consisting to a glass jar underpressure at $P_{\mathrm{up}} = 0.3\,\mathrm{bar}$.

The total water flow is regulated at 90 l/h to get a flow of 45 l/h in each super-drawer of the module.

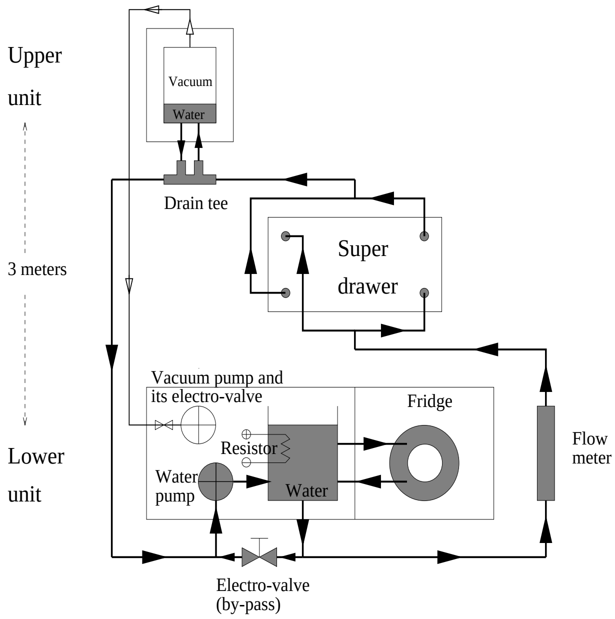

Figure 1: Scheme of the LCS water installed in the TILECAL test beam.

3.2 Working and results

The results obtained for the 4 temperature probes are shown in figure 2.

The time to obtain stabilisation of temperature is about 2 hours after swithcing on all the electronics. When the temperatures have reached their working values, we observe a good stability over the 10 hours, see table 2.

We measure for the first time the temperature on the high voltage cards, which is very close to the drawer temperature, and the temperature near the photomultiplier which is about 3^0C less than the temperature near the 3-in-1 board. This last effect is due to the divider card which isolates the photomultiplier from the electronics card in the PMT block.

We can recall that the temperature stability obtained during the 1997 and 1998 test beam periods was:

$$\sigma_T < 0.25^0\text{C} \quad \text{in 1997}$$
$$\sigma_T < 0.30^0\text{C} \quad \text{in 1998}$$

The worst result obtained in 1998 was due to a day/night variation produced by 10 meters of non isolated plastic tubes sensitive to the North Hall temperature.

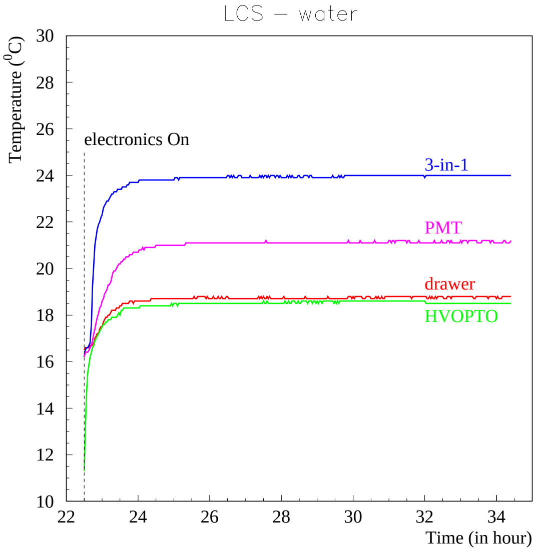

Figure 2: Temperatures behaviour with the water cooling system.

4 Per-fluorocarbon (C_6F_{14}) system

4.1 Presentation

For the LCS using the per-fluorocarbon, a rack working with a programmable logic control (PLC) has been designed by the CERN cooling team of M. Bosteels.

The principle is similar to the water system except that their is no upper unit [4], see Fig. 3:

- a tank contains the C_6F_{14};
- the liquid is regulated at a given temperature: $T_{C_6F_{14}} \approx 18^0$C for our test;
- the circulation of the liquid is ensured by a circulation pump;
- the tank is underpressure: $P_{\text{tank}} \approx 0.5$ bar in our test.

The figure 4 shows a photo of the C_6F_{14} rack below the table supporting the TILECAL module.

4.2 Working and results

The first test with the C_6F_{14} showed bad stability of the temperatures, see left plot on figure 5. We observed a temperature cycle with a period of about 1 hour. After

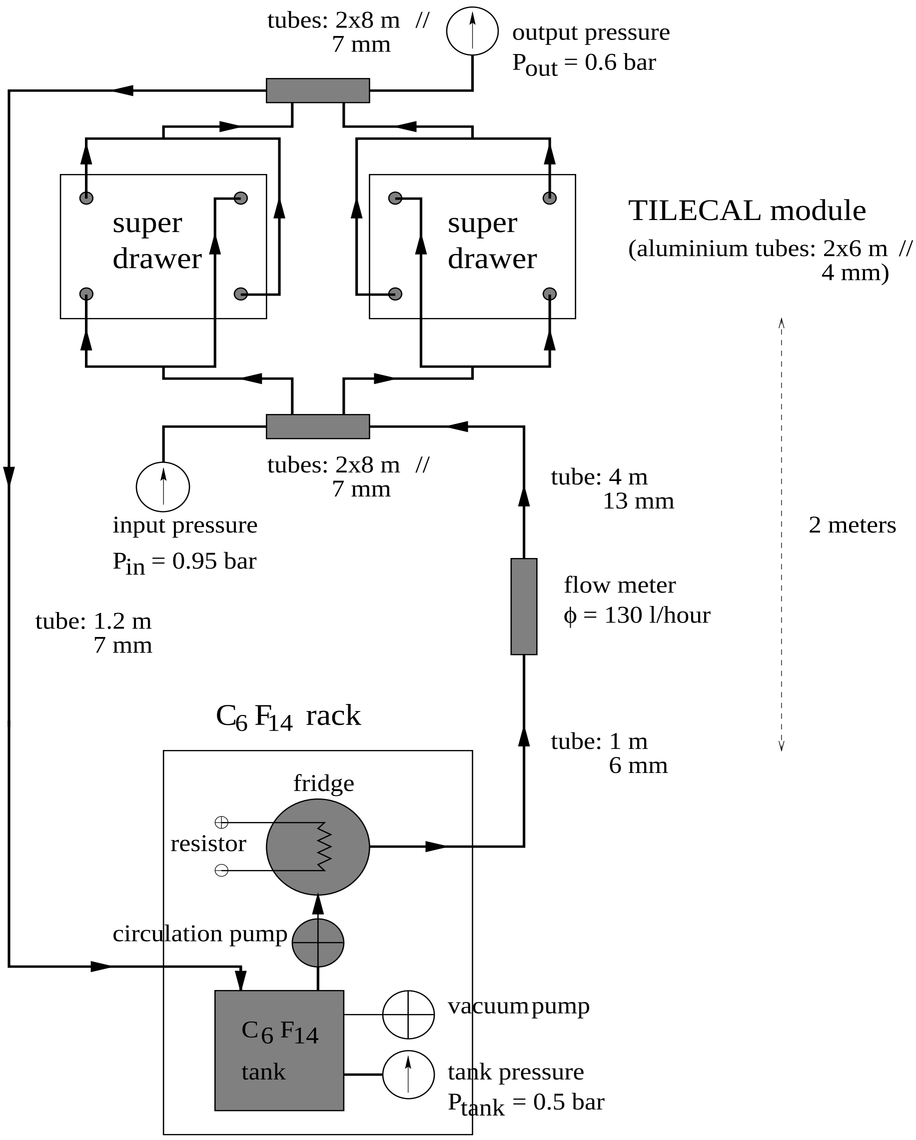

Figure 3: Scheme of the LCS per-fluorocarbon used in the test with the TILECAL.

Figure 4: Photo showing the C_6F_{14} cooling rack below the TILECAL module.

investigation, this phenomena was found to be due to a leak at the level of the flow meter. The effect of the leak, meaning that the air entered the cooling circuit, was to trigger the vacuum pump of the tank very frequently. Furthermore, for each cycle, we observed a rapid increase of the temperature followed by a slow decrease. This effect is due to the fact that during the working of the vacuum pump, the circulation pump is stopped, and then all the liquid was down to the lower tank. In these conditions, during this time the TILECAL module is not cooled and the temperature increases. Later, when the vacuum pump is stopped and the circulation pump on, the module is again cooled and the temperature decreases.

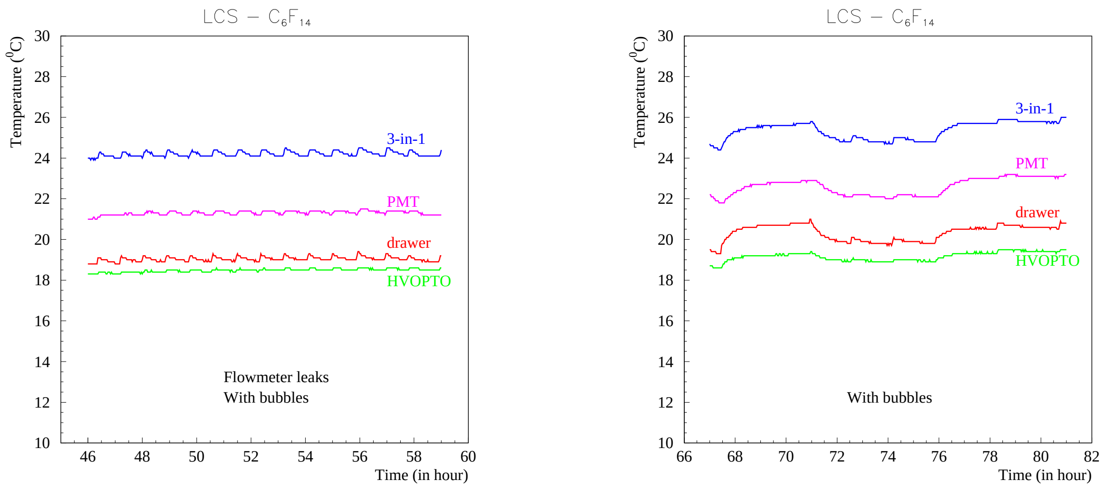

Figure 5: Temperatures behaviour with the C_6F_{14} cooling system: left plot with the problem of flow-meter leaks, right plot with the problem of bubbles.

In a second step, we have tried to optimise the working mode of the cooling system, but a problem of bubbles appearing at the output level of the TILECAL module has not been solved. The temperature behaviour is presented by the right plot on figure 5. We observe a poor stability of the temperatures with two cyclic phenomena: one with a period of 2 hours corresponding to the working frequency of the vacuum pump and another one with a period of 8 hours which has not been explained. We can also notice that the temperature on the HVOPTO card is more stable, due to the fact that the probe is outside the super-drawer in the air, and then less sensitive to the cooling of the frame.

In this configuration, the parameters characterising the cooling system were:

- per-fluorocarbon flow $\phi_{C_6F_{14}} \approx 130\,\mathrm{l/h}$,
- tank pressure $P_{\mathrm{tank}} = 0.55\,\mathrm{bar}$,

- input pressure $P_{\text{in}} = 0.95\,\text{bar}$,
- output pressure $P_{\text{out}} = 0.60\,\text{bar}$.

Concerning the presence of bubbles at the output level of the module, we can say that these bubbles are not air bubbles due to a leak. Indeed, if it was the case, the duty cycle of the vacuum pump would be higher.
The explanation we have found is the following.
The two output tubes (with a diameter of 7 mm) coming from each super-drawer of the module arrived in a tee to give a single tube (with a diameter of 13 mm) going back to the C_6F_{14} rack, see left scheme on figure 6. A the tee level, the liquid undergoes an expansion phenomena implying the transition of the liquid in gas. Furthermore, this transition is favoured by the low value of the vaporisation pressure of the C_6F_{14}: $P_{vap} \approx 276\,\text{mbar}$ (1 Torr = 1000/760 mbar) at 20^0C.
To solve the problem, we changed the tee so that the diameter of the return tube is the same as the two output tubes coming from the super-drawers (7 mm), see right scheme on figure 6. In this case, there is no expansion phenomena of the liquid, then no transition liquid-gas, and the problem of bubbles is cured.

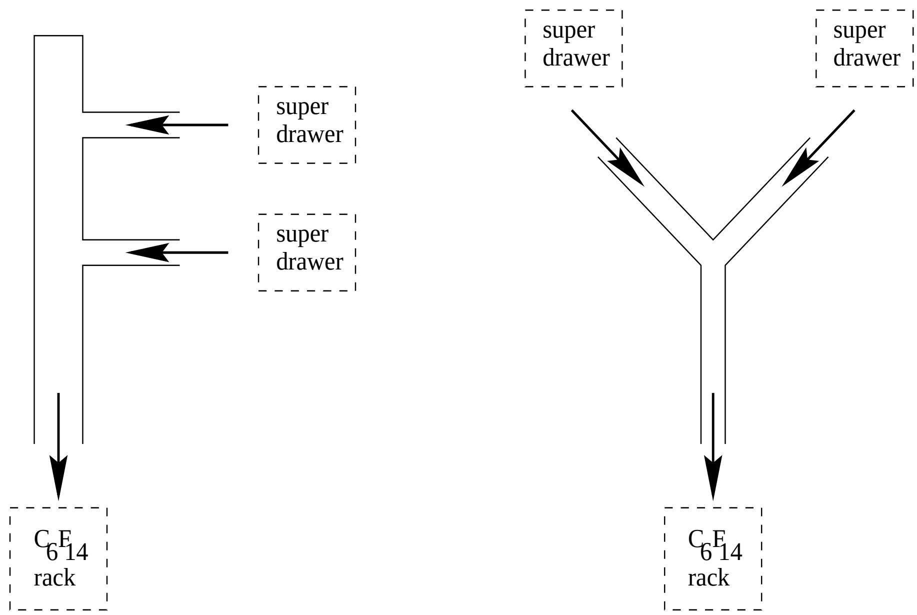

Figure 6: Schemes of the tees used during the C_6F_{14} test: on the left with bubbles, on the right without bubbles.

In these conditions, we can see on figure 7 that the temperature stability now obtained with the per-fluorocarbon system is similar to the stability with the water system, see table 2. Furthermore, the time to obtain stability after switching on the electronics is the same, namely about 2 hours.

In this working mode, the temperature cycle corresponding to the working period of the vacuum pump is about 2 hours, but the amplitude is smaller compared to the first try. Nevertheless, the problem of liquid going down in the tank during the operation of the vacuum pump is still present.

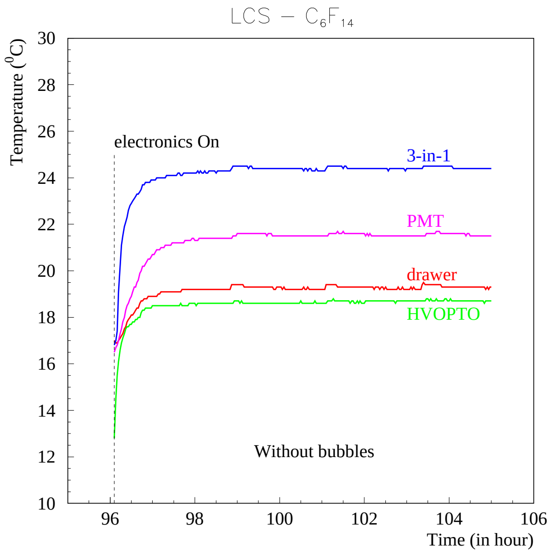

Figure 7: Temperatures behaviour with the C_6F_{14} cooling system, without the problem of bubbles.

After this test, we have tried to change the C_6F_{14} flow, to study its impact on the temperature in the TILECAL girder. But we have not succeeded to get a working mode without bubbles in other conditions.

4.3 Comparison with water

The stabilities of the temperatures obtained for each probe, namely in the different part of the girder, are summarised in the table 2.
From these results two remarks can be made:

- The stability with the water cooling system is better with respect to the perfluorocarbon one. But in this last case, the bigger instability is due to the temperature cycle phenomena.
- The temperature obtained with the C_6F_{14} cooling system are slightly higher compare to those get with the water. This difference can be cured by increasing the liquid flow, but this test has not been done due to the bubble problem.

Probe	H_2O	C_6F_{14}
drawer	$(18.74 \pm 0.05)^0$C	$(19.28 \pm 0.07)^0$C
HVOPTO	$(18.54 \pm 0.05)^0$C	$(18.65 \pm 0.06)^0$C
drawer	$(23.96 \pm 0.05)^0$C	$(24.40 \pm 0.08)^0$C
PMT	$(21.11 \pm 0.05)^0$C	$(21.53 \pm 0.08)^0$C

Table 2: Results of the temperatures stability for each probe with the two cooling systems.

5 Temperature and consumption

The last test was dedicated to the study of the power consumption of each electronic part. For that, we have switched off successively each electronic part to see its impact on the temperature in the different regions of the girder.

The result is illustrated on figure 8, and the following effects can be noted:

1. The high voltage distributor cards have only an effect in the PMT block, and especially in the photomultiplier region, due to the resistor of the divider.
2. The pipeline (digitizer) boards have an effect on all the girder regions, but this effect is more important on the HVOPTO probe. It is normal because this probe is directly in the air of the girder, like the pipeline boards.
3. The 3-in-1 boards give the main contribution to the dissipated power in the girder, and mainly in the PMT blocks. We can also note that the time constant characterising the temperature decrease is different for the two regions of the PMT block: 3-in-1 and PMT probes. That is due to the divider card which isolates the two parts of the PMT block.

The temperature in the North Hall during the test in December was about 18^0C, while the expected temperature for the TILECAL in the ATLAS cavern (see paragraph 20.4 and references within of Ref. [6]) will be between 23.6^0C and 27.5^0C, namely $(25.5 \pm 2.0)^0$C. Then from the previous results, the expected temperatures in the different regions of the girder will be:

$(20 \pm 1)^0$C	in the frame of the drawer,
$(20 \pm 1)^0$C	in the environment air of the high voltage distributor cards,
$(25 \pm 1)^0$C	in the PMT block region of the 3-in-1 boards,
$(23 \pm 1)^0$C	in the PMT block region of the photomultiplier.

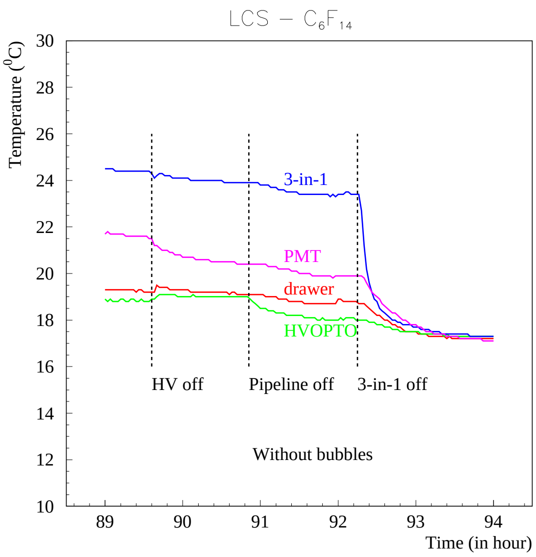

Figure 8: Temperatures behaviour with the C_6F_{14} cooling system, when the electronics boards are switched off.

6 Conclusion

To conclude, we have demonstrated that the Leakless Cooling System working with the per-fluorocarbon can be used for the TILECAL hadron calorimeter of the ATLAS experiment.

The problems occurred during the test (cycles temperature and creation of bubbles) seem to have a solution [5].

The last big problem is the price of the liquid (C_6F_{14}) in this cooling system compared to the water solution; plus the cost increase due to the design itself: special pump, nature of the flexible tubes, ...

Acknowledgements

We would like to thank Jan Godlewski and Antti Onela for providing the per-fluorocarbon cooling rack, initially designed for the ATLAS TRT and CMS MSGC sub-detectors test.

References

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[4] This reference has been provided by P. Bonneau and M. Bosteels, http://nicewww.cern.ch/~pbonneau/CWGWeb/SFHomePage.htm.

[5] From the conclusions given by M. Bosteel at the LHC cooling meeting, 10 March 1999.

[6] ATLAS technical co-ordination T.D.R., CERN/LHCC/99-01, ATLAS TDR 13, 31 January 1999.