A mono-phase cooling system for detector front-end electronics: the example of the ATLAS TRT detector

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Abstract

This work presents the results of the test on the cooling of ATLAS TRT electronics. The test set-up and the control equipment are described.

A model of a standard cooling unit designed for all ATLAS detectors is also presented together with its features imposed by the various boundary conditions connected with the experimental zone, presence of magnetic field, limited access and localization of the various detectors.

I. INTRODUCTION

The heat produced in the TRT (mainly by the front-end electronics and the straws) must be removed by an efficient cooling system in order to ensure thermal neutrality of the TRT towards the rest of ATLAS and to avoid hot spots damaging the electronics components. In this work we describe the complete cooling system of the detector and discuss its efficiency. The efficiency of the cooling system for the front-end electronics of the TRT end-cap detector was studied by Finite Element Analysis and verified with experimental tests.

The TRT end-cap front-end electronics is located at the outer perimeter of the end-cap wheels and is divided in two printed circuit boards, the DTMROC board and the ASDBLR board (see Fig.1).

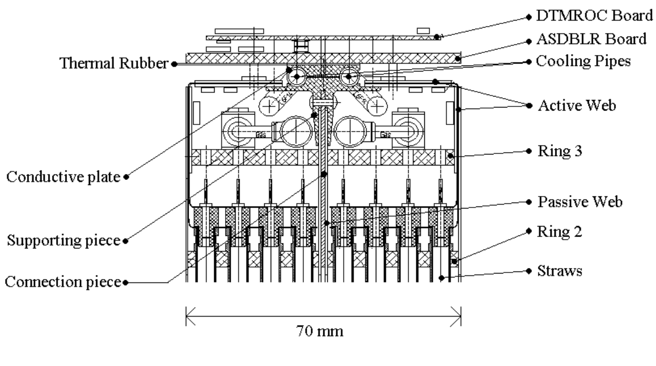

Figure 1: Layout at the outer radius of TRT end-cap wheel with schematic view of electronics cooling.

The total number of front-end electronics boards in the TRT end-caps is 5376 and the expected heat dissipation is around 6.4 watts per the one pair of boards. Operating at higher temperatures than specified in [1] 45°C could shorten the lifetime and decrease considerably the reliability of the electronics. The electronics of each 8-plane end-cap wheel will be cooled by two loops of pipes, each one covering 180 degrees of the wheel (see Fig 2).

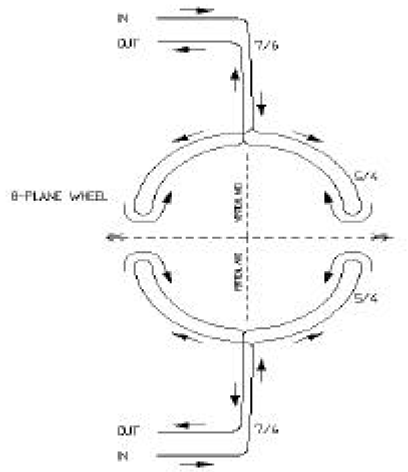

Figure 2: Cooling system circuits.

The fluorocarbons C_6F_{14}, and C_8F_{18} are considered as cooling liquid. In general fluorocarbons are characterised by very high dielectric constants and therefore often used in industry for the immersed cooling of electronics components.

In the proposed cooling design of the TRT end-cap wheel front-end electronics, the heat generated by the electronics will be transferred through electrical connectors, via the so-called active web (see Fig.1), down to a conducting aluminium plate, which is connected to the cooling pipes. The cooling liquid will thereafter remove the heat from the system.

II. FINITE ELEMENT MODEL

A finite element model was constructed in order to study the heat flow and the temperature distribution of the front-end electronics [2]. Using the symmetry of the boards and electronics, it was sufficient to study only one fourth of the total. This model that consists of 30062 nodes and 23816 elements, with an average element length of less than 1 mm, was made in 3D using the commercial software ANSYS*. The thermal conductivity's of the electronics boards and the active web were calculated by the application of multi-layer theory [3] based upon the different amounts of material in each layer.

According to the Technical Design Report [1] (section 12.9.6), the maximum value for the average power dissipation in the front-end electronics was 60 mW per channel (45 –ASDBLR and 15 – DTMROC). In 1999 the expected power dissipation of front-end electronics was increased to 100 mW/channel with the distribution 40 – ASDBLR and 60 – DTMROC. For ASDBLR, this means 320 mW/chip and for the DTMROC 960 mW/chip. Based on a 5 ºC temperature increase of the cooling liquid inside the detector and an inlet temperature of 15 ºC, the required flow is 1.81 10^{-5} m^3/s. All surfaces, except the ones of the cooling pipe, are treated under adiabatic conditions, which means that heat is removed from the system only by the cooling liquid. This corresponds to the worst case scenario, since some convection will decrease the temperature of the electronics.

III. RESULTS OF THE FEA CALCULATIONS

As it was shown in [2], a conductive rubber placed between the ASDBLR board and the aluminium plate significantly improves the heat transfer and as a result the maximum temperature of the model visibly drops. Therefore the calculations were performed for the model where a rubber having the conductivity of about 1 W/mK was inserted between ASDBLR board and the cooling plate. In Fig.3 we present the simulated geometry and the result. For the power dissipation discussed (40 mW/channel ASDBLR and 60 mW/channel DTMROC) a maximum temperature of 75ºC was found on the DTMROC chip.

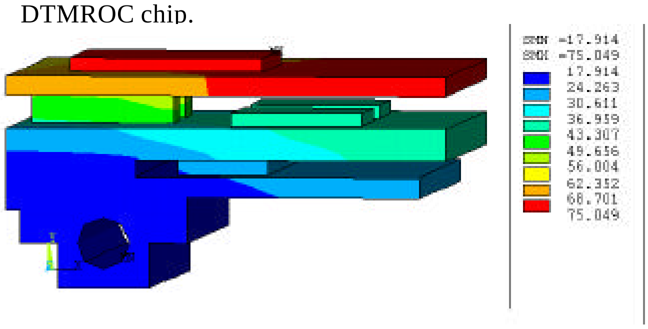

Figure 3: Temperature distribution obtained for the model with rubber inserted only between ASDBLR and the cooling plate.

Since it was not possible to improve the thermal contact between the ASDBLR board and the cooling plate, an alternative solution was to improve the thermal contact between the DTMROC and ASDBLR boards. Once again a thermo-conductive rubber was used. All the volume between electronics boards, with the exception of connectors and ASDBLR chips, was filled with rubber.

* ANSYS is a trademark of the Swanson Analysis Systems Inc

The results are shown in Fig.4. The maximum temperature is dropping to 56 ºC. This value is still above the limit of 45 ºC but with the expected decrease of the power generated by the electronics this result is very promising.

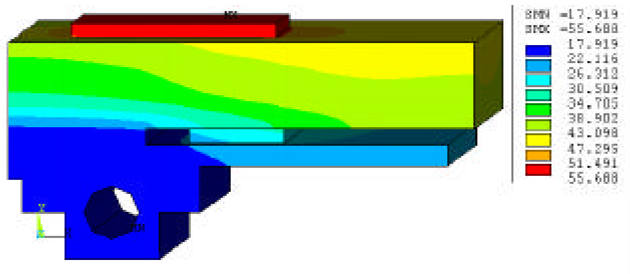

Figure 4: Temperature distribution obtained for the model with rubber inserted between the ASDBLR and DTMROC boards.

IV. EXPERIMENTAL VALIDATION

To verify experimentally the results of the FEA calculations a thermal prototype of the front-end electronics boards was manufactured. Initially, resistors were taken to simulate the heat produced by the chips [2], later the real electronics was used. The results for the latter case are presented in Fig.4. The experimental set-up is shown in Fig.5.

Figure 5: Experimental set-up. Conductive rubber can be seen between electronics boards.

Here water was used as a cooling liquid. The flow rate was adjusted to give the same heat transfer coefficient as in the case of fluorocarbon.

Table 1: Comparison of simulations and measurements results.

Heat load case ASDBLR/DTMROC mW/channel	Maximal temperatures on electronics set [ºC]	
	ANSYS simulation	Measurements
31/44 *	58.8	54.5
40/60 *	75	
31/44 **	45	47
40/60 **	55.9	54.5
36/40**	44	

* Without thermo-conductive rubber between electronics boards
** With thermo-conductive rubber between electronics boards

The measured values are the steady-state temperatures achieved at equilibrium. The temperature of the cooling water at the inlet of the cooling pipes was 15 °C. The measurements were performed with and without thermo-conductive rubber placed between the ASDBLR and DTMROC boards.

V. DESCRIPTION OF A STANDARD COOLING UNIT.

To cool the whole TRT two cooling units with a capacity of around 30 kW will be placed at the ground level of ATLAS experimental cavern (Fig.7). They will have to operate in a hostile environment, common to all LHC experiments. Because of a temporarily inaccessible area they have to be filled and drained automatically. The risk of a leak has to be as remote as possible. For fluorocarbons used in TRT cooling system the cost of leaks can be substantial [4]. In addition the cooling units will have to work in strong magnetic field of 500 Gauss and will have to sustain the total radiation dose close to 1.5 Grey in 10 years [5].

At the lowest point of the cooling installation there is a reservoir with a capacity equal to the total volume of the circuit. An absolute pressure of 500 mbar is kept in this reservoir equipped with a level indicator and a pressure sensor. A safety valve tarred at 70 mbar protects the reservoir against overpressure. A cooling liquid is pumped into the circuits through a filter and a plate exchanger by means of a pump (see Fig.6). The heat exchanger is connected to a chilled water circuit.

A flow rate of chilled water is remotely controlled according to the temperature of the outgoing liquid using a pneumatic valve. Two main circuits are equipped with a valve activated by a double effect servomotor. An additional circuit allows a remote control of quality, input and recuperation of a liquid.

A differential pressure valve regulates the pressure in the outlet collector. Each distributor situated on the platform is equipped with a pneumatic shut-off valve and a control valve regulated in the function of pressure loss in sub-circuits. Flow rate of the latter is regulated by an equilibrium valve. Returns can be individually isolated with the use of a hand-operated valve.

Before starting the operation of the installation all pneumatic valves are closed, the vacuum pump is switched on and the absolute pressure in the reservoir is set at 500 mbar. If the pressure stays constant the circuits are opened one by one, the pressure being controlled all the time. Increasing pressure means the presence of a leak or an open circuit. When all the circuits are opened the liquid can be introduced into the detector. Air present in the circuit comes back to the reservoir and its excess is evacuated by the vacuum pump. A decrease of the level of liquid during the operation means that there is a leak in one of the inlet circuits. In such a case the circuits can be isolated one after the other in order to find a cause. An anomalous increase of the pressure in the reservoir indicates a leak in a return circuit.

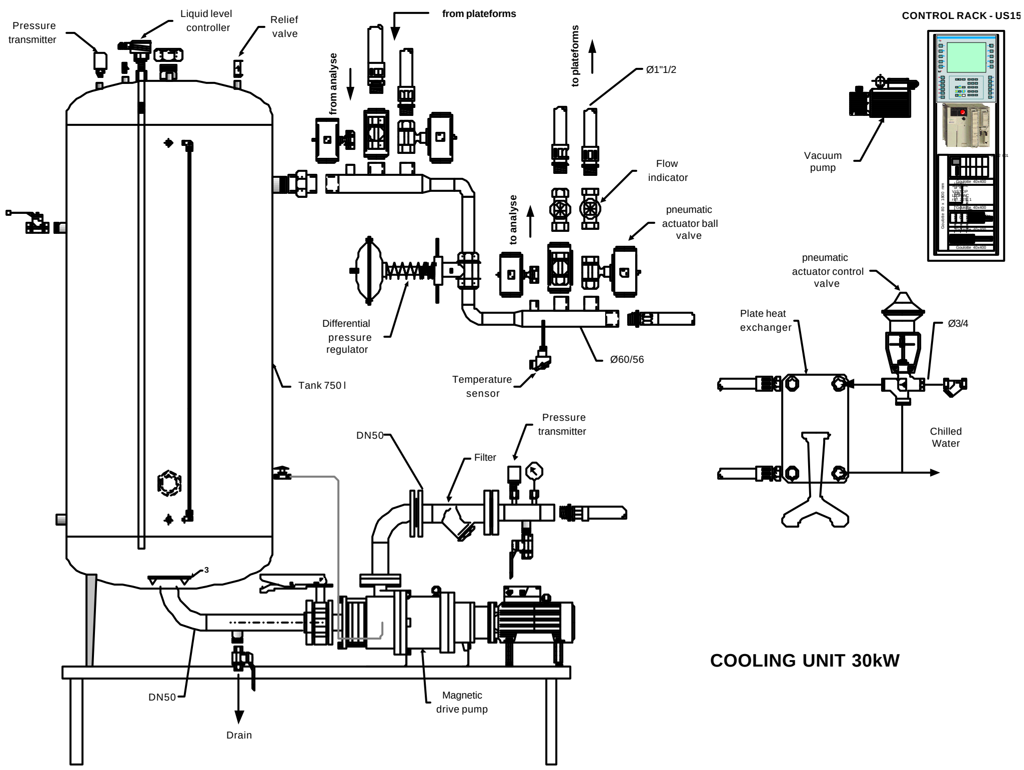

Figure 6: The cooling unit with its main components

In case of a sudden change of the level or pressure in the reservoir the circulating pump is switched off and automatically in the whole installation pressure becomes lower than atmospheric. The liquid in the circuit will come back to the reservoir, except that present in possible pockets.

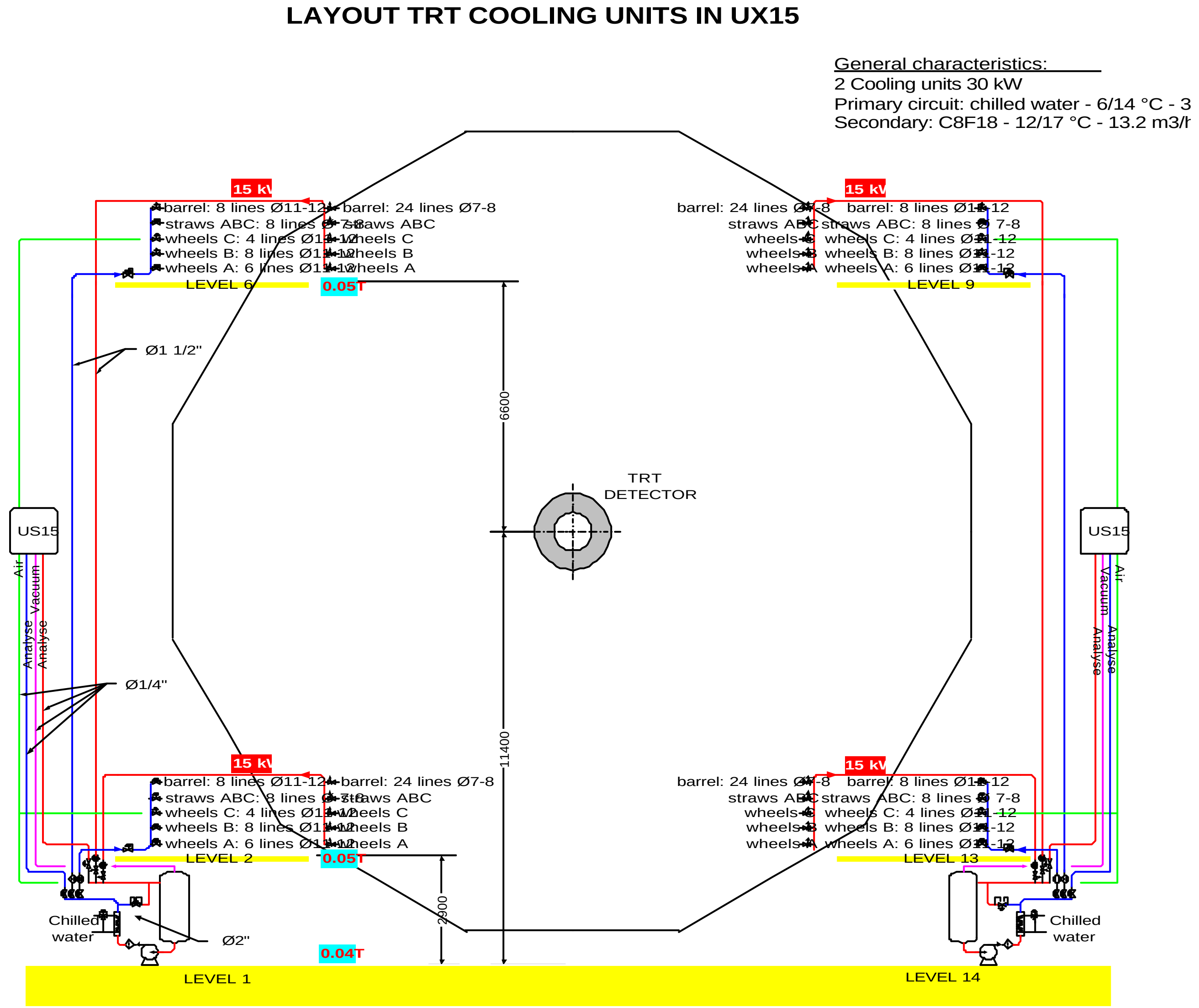

Figure 7: Layout of the TRT cooling system in ATLAS experimental cavern

In order to start the pump again it is necessary to perform the starting procedure except filling the reservoir. All these manipulations are done from distance and can be automated by a PLC (Programmable Logic Controller). The proposed modular equipment can be used for all cooling installations in the ATLAS regardless whether fluorocarbons, demineralised water or water with algaecides or anticorrosion additives are used. Arrangement of elements of the cooling unit should also allow their insulation in the case of cooling with the use of low temperature liquids, for instance cooling of the thermal shields of silicon detectors.

Fig.8 shows a cooling unit similar to one proposed for TRT. It is used by COMPASS experiment at CERN [6]. This unit was specially designed as a real size prototype for LHC standard cooling units.

VI. Conclusions

The work shows that by creating an additional heat path between the electronics and the cooling plate with the use of conductive rubber it is possible to cool electronics down to acceptable temperatures.

A good agreement between the calculations and the test results was obtained. The finite element model was experimentally validated as a powerful tool that may be used for further investigations of the impact of any changes in the design.

A standard cooling unit was designed for TRT cooling system. Units based on the same principle can be adapted to all the cooling systems of the ATLAS and others LHC experiments.

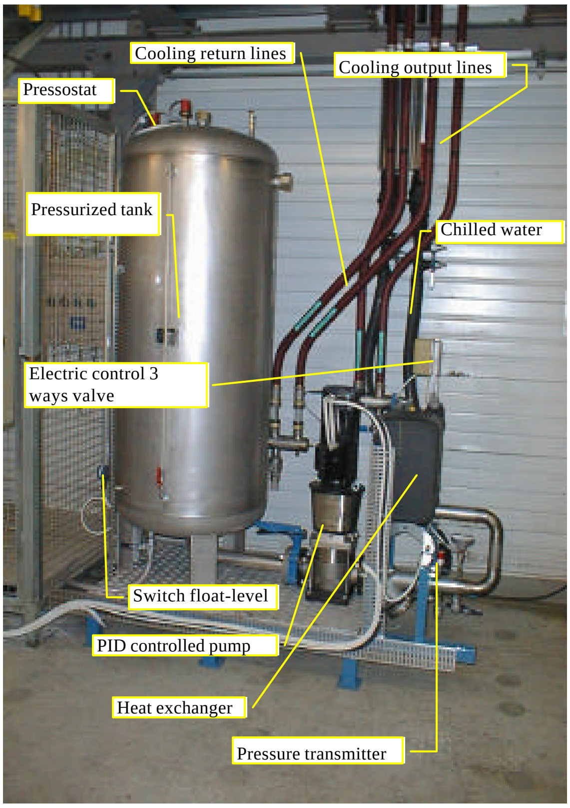

Figure 8: Cooling unit for COMPASS experiment. A real size prototype for LHC standard cooling units

VII. REFERENCES

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