Studies on the CMS Tracker Upgrade Project

Francesco Costanza
Universitá degli Studi di Bari, costanza_f@hotmail.it

I have been working in the CMS sLHC tracker group. My work dealt with making up a laboratory test setup that will allow to measure the thermal and mechanical performance of test structures and also prototype modules. During the first period of my staying here I helped calibrating 10 Pt 100 *temperature sensors. Using these sensors I measured the thermoconductivity coefficient of some rods of different materials in the last 4 weeks. Moreover, to support the thermoconductivity measures I have also made a computer simulation with the finite element software* GetDP *in which convective and radiative heat transfer is taken into account.*

Introduction

The current Large Hadron Collider (LHC) set up is expected to produce proton-proton collisions at a center of mass energy $E_{CM} = 14\,TeV$ with a luminosity up to $\mathscr{L} = 10^{34}\ cm^{-2}\ s^{-1}$. All the detectors have been designed to cope with the resulting high event rates and high radiation damage. However, an upgrade (sLHC, scheduled for 2020 and beyond) is already under study to have a better chance to see rare processes and improving statistically marginal measurements. This upgrade will improve the machine exentially by increasing the luminosity, and so the evernt rate, by a factor of 10.

At this luminosity, there will be about 200 collisions per 25 ns, producing about 1200 charged tracks per unit of pseudo rapidity. In the CMS tracker, all the silicon strip sensors and electronics were not designed to fulfill in terms of occupancy, readout capabilities and radiation hardness. Moreover, key elements of the current detector will not survive more than a few years at full LHC intensity. At the time of the envisaged sLHC upgrade, the silicon strip modules of the current CMS tracker will already suffer from substantial radiation damage. Therefore, the CMS silicon tracker will have to be completely rebuilt.

During the "DESY Summer Student programme" I have been working in the CMS sLHC tracker group which investigates new layouts for silicon strip detector modules for the next CMS tracker. The development of these modules holds several challenges, such as providing **efficient cooling** of the silicon sensors and front-end electronics at low temperatures to ensure their radiation hardness, achieving **high mechanical stability** of the multi-material compound modules under temperature variations, and strongly **reducing the material budget** compared to the current module design.

My work dealt with making up a laboratory test setup that will allow to measure the thermal and mechanical performance of test structures and also prototype modules. During the first period of my staying here I helped calibrating 10 *Pt 100* temperature sensors. Using these sensors I measured the thermoconductivity coefficient of some rods of different materials in the last 4 weeks. Moreover, to support the thermoconductivity measures I have also made a computer simulation with the finite element software *GetDP* in which convective and radiative heat transfer is taken into account.

1 Laboratory setup

Figure 1 shows our laboratory setup. It consists of:

- 1 conventional chiller, Julabo FP50-MC;
- 1 vacuum chamber with electrical feedthroughs to guide cable inside;
- 1 vacuum pump to reduce the influence of convection, 50mbar was the lowest pressure reached;

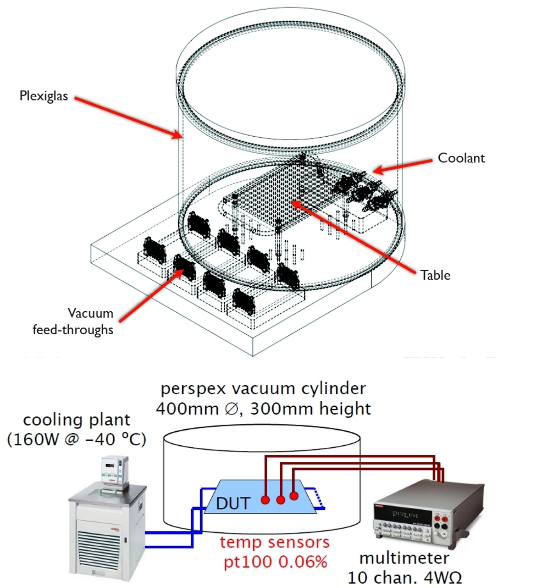


Figure 1: Laboratory setup

- 10 *Pt 100* sensors for temperture mesurments, precision of better than 0.06% at 0 ℃;
- 1 multimeter with 10 channels to read all the temperature sensors, Keithley 2700 used in 4W mode.;
- 1 aluminum table coupled with a copper cooling loop connected to the chiller, table legs made of perspex (insulator material);
- 1 computer connected to the chiller and the multimeter to control them, acquire and store data.

The first step had been checking if the chiller was working and so if it was possible to efficiently cool down the table. To do this, all the sensors were placed in different positions all along the table and the chiller was turned on. The same temperature for all the sensors was expected but on the contrary the *Pt 100* sensors gave values quite different the one to the other. This problem could be solved calibrating the termometers.

2 *Pt 100* calibration

Pt 100 sensors are beeing used for the temperature mesurements. A *Pt 100* sensor is a resistance thermometer, i.e. a two-terminal electronic component which exploits its predictable change in electrical resistance with changing temperature for taking temperature mesuraments. *Pt 100* sensors are so called because they are made of platinum and their electrical resistance is $100\,\Omega$ at 0 ℃. Resistance thermometers are more precise than thermocouples because the formers have higher accuracy and repeatability.

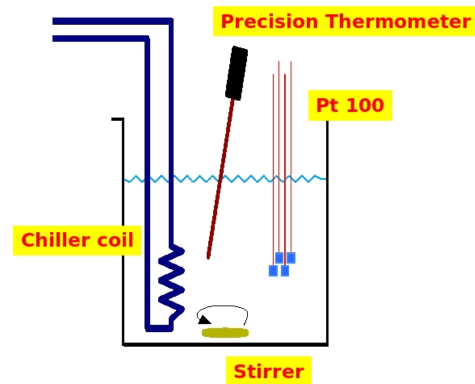


Figure 2: Sketch of the calibration setup

Figure 2 shows a picture of the calibration setup. An aleady calibrated thermometer with an accuracy of 0.01 ℃ was used to calibrate the sensors. All the *Pt* 100*s* and the already calibrated thermometer were put in a beaker filled with ethanol. The ethanol was cooled down by the chiller, silicon oil was used as a coolant. The whole setup was enclosed in an insulator chamber to reach low temperature more easily.

The sensors temperature versus the reference temperature is plotted in Figure 3.

As it can be seen in this graph, the mesurements of the sensors were quite different the one to the other. The calibration was made through a linear fit of this plot. This linear fit function allow us to obtain the correct temperature knowing the measured one. The sensors temperature after the calibration is shown in Figure 4.

The distribution of the difference between the reference temperature and the sensors temperature reconstructed after calibration shows a gaussian shape centered on zero for all the sensors but the 8th. The residual distribution for sensor 5 and sensor 8 are plotted in Figure 5. The residual plots for the other sensors are similar to the sensor 5 one.

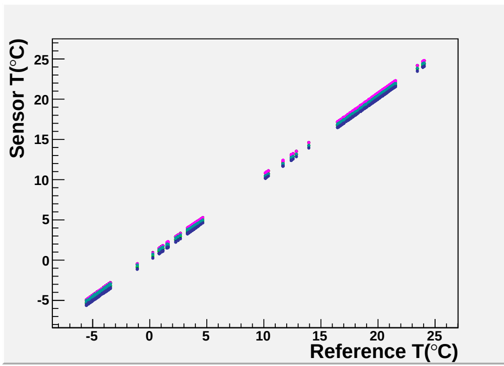


Figure 3: Non-calibrated sensors temperature vs calibrated thermometer temperature

Sensors	T℃	T℃	T℃
0	4.0	12.0	22.0
1	12.5	20.3	30.0
2	8.4	25.6	25.5
3	8.9	16.4	25.6
4	23.0	16.7	25.5
5	48.0	48.0	48.0
6	2.3	10.5	19.5
7	2.3	10.5	19.5
9	1.0	10.0	19.0
k	228	235	242

Table 1: Thermoconductivity mearurements.

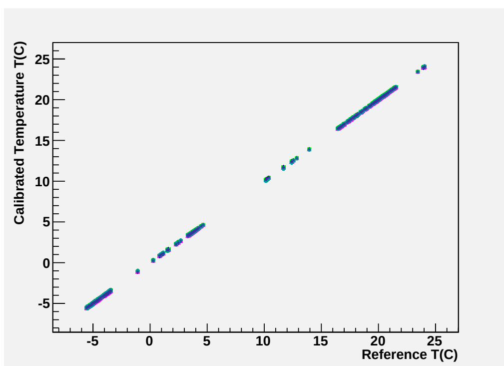


Figure 4: Calibrated sensors temperature vs calibrated thermometer temperature

From these graphs it is possible to understand that:

- Sensor 8 doesn't work well and for this reason it was not used in the following mesurments;
- All the other sensor show very correctly calibrated with an accuracy of ~ 0.015 ℃ that is enough for our purposes.

3 Thermal conductivity coefficient

3.1 Laboratory measurments

Thermoconductivity is one of the most important material properties that have to be taken into account to design an efficient cooling system. A laboratory setup for measuring the thermal conductivity coefficient has been installed. Figure 6 shows this setup. The aluminum table is kept at a costant temperature using a chiller. A 10cm long rod made of the material under study is put standing on the table. The rod has a radius of about 1cm. On the top of the rod an aluminum cylinder is set. The cylinder is 1.5cm high and has the same radius as the rod. Above the cylinder a resistor of 100Ω is placed. The whole setup is heated by the resistor via Joule effect with a power of 6.1W. The aim of the aluminum cylinder is to make the heat coming from the resistor flowing more uniformely through the top of the rod.

In Figure 6 is also shown where the temperature sensor where placed:

"0": 1 on the top of the rod;

"1": 1 on the bottom of the rod;

"2", "3": 2 in the middle of the rod;

"4": 1 along the power cable 20 cm away from the resistor;

"5": 1 as close as possible to the resistor;

"6", "7", "9": 3 on the table.

From the sensors "4" and "5" and knowing the wires material and cross-section it is possible to calculate the fraction of the generated heat flowing through the power cables. The value of this fraction is $\sim 1\%$.

Sensors "0", "1", "2", "3" are used for the thermal conductivity calculation. The results are shown in Table 1:

As can be seen from the Table 1 the temperature gradient is not uniform along the rod as it would be expected if convection and thermal radiation were negligible. Furthermore, a quite lower thermal conductivity coefficient is expected for aluminum $k \sim 150 W k^{-1} m^{-a}$. This means that convection could play an important role even at low pressure.

3.2 GetDP *simulation*

A *finite element software* was used to simulate convective and radiative heat transfer. Taking into account:

- air temperature inside the vacuum chamber;
- heat transfer coefficient of the air;
- emissivity coefficient of all the materials;
- dissipated power by the resistor $6.1W$;
- all the known thermoconductivity coefficients

and tuning the unknown one it was possible to obtain a simulation which fits with data. The equations solved by the GetDP are:

$$\begin{array}{ccl} \text{Conduction} & \overrightarrow{q} & = k \cdot \nabla T \\ \text{Convection} & \frac{dQ}{dT} & = -h(T_{env} - T(t))ds \\ \text{Radiation} & \frac{dQ}{dT} & = \epsilon\sigma(T^4(t) - T^4_{env})ds \end{array}$$

As far as the constraints is concernt:

- Edges of the table at measured temperature $1℃$;
- 20cm away from the resistor at $23℃$

The results of this simulation are shown in Figure 7a and 7b. .

As can be seen from these figures taking into account convection and radiation the non-uniform temerature gradient along the rod can qualitatively be explained.

4 Conclusions and outlooks

Nine of ten temperature sensors have been correctly calibrated and they have an accouracy of $\sim 0.015℃$. The other one is correctly calibrated (residual plot centered over zero) but has a worse accouracy $\sim 0.1℃$.

The setup for mesuring the thermal conductivity coefficient has been tested. Convection and thermal radiation were find to play an important role. An improvement could be achived enclosing the rod, the heat spreader and the resistor in an insulator enveopment.

A quite satisfactory simulation of the setup has been developed, improvement of the simulation could be reached by careful tuning of the model parameters.

In the future, the setup for deformation mesurments with optical technique will be made.

Acknowledgments

I would like to express all my gratitude to my supewrvisors Andreas Mussgiller and Jan Olzem for their help, their kindness and their precious advises. I want to thank all the people that work at the CMS Group in DESY for the friendly atmosphere and above all my college Stephanie Yuen. A special thank to my friend Victor Gutierrez Diez for his support. Finally my gratitude goes to Dr J.Meyer for organizing this summer program.

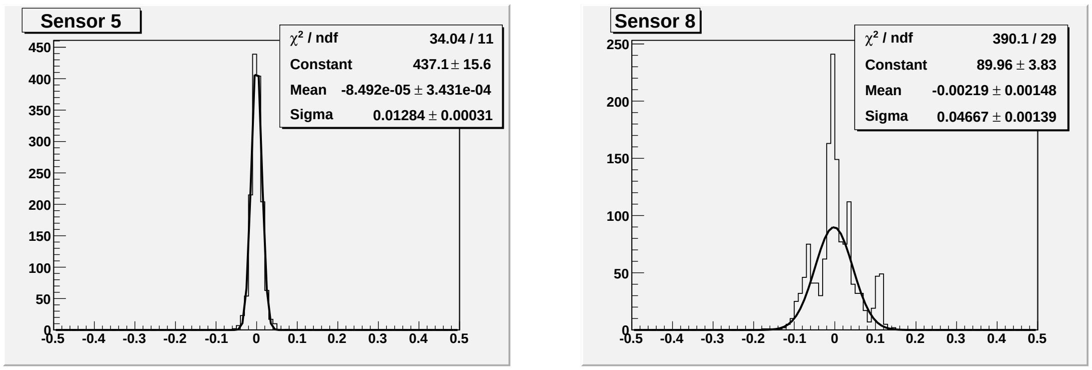


Figure 5: Residual plots.

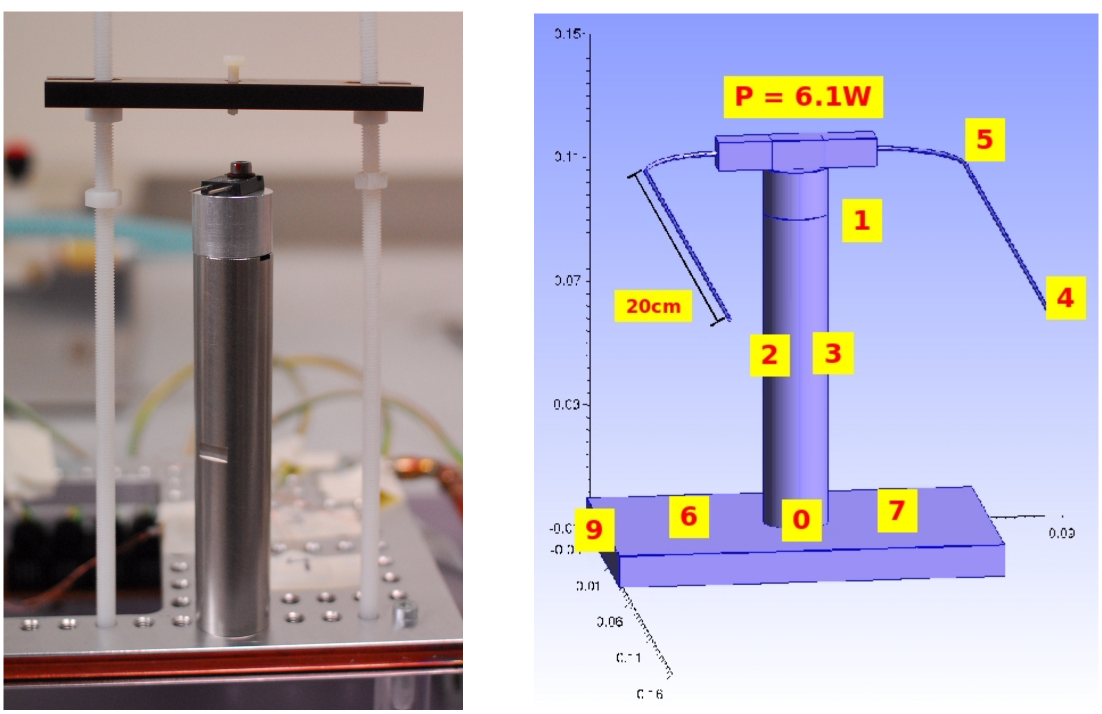
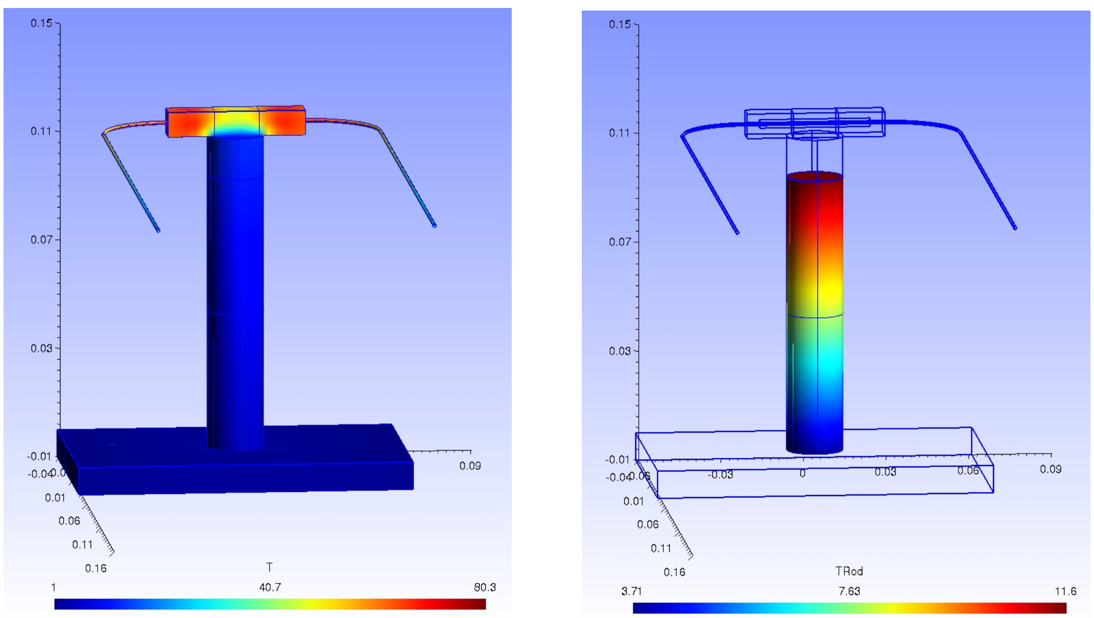


Figure 6: Laboratory setup for thermoconductivity measurments



(a) Overall simulated temperature.

(b) Simulated rod temperature

Figure 7: GetDP simulation: edges of the table at fixed temperature 1℃, $6.1W$ dissipated by the resistor. Convection described by Newton's law, radiative heat transfer described by Stefan-Boltzmann law.