Test of Prototype Heating-Blankets for the Warm-Up of Complete C Frames of the LHCb Outer Tracker

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Abstract

In one of the treatments to improve the aging performance of the LHCb Outer Tracker modules a flushing at an elevated temperature (40 °C) for about 10 days is proposed. To warm-up the already installed modules in situ a heating setup which consists out of special electrical blankets to wrap a complete stereo-layer has been developed. The blankets with a length of 6 m and a width of 1 m have an active heating area of about 5 m^2. The area is subdivided into 4 heating areas which are independently controlled each by one temperature sensor.

Two prototypes blankets have been tested: A mockup of a mini stereo-layer with 4 Outer Tracker modules of 5 m length was wrapped with the electric blankets and was heated to the aimed temperature of 40 °C. The temperature uniformity was measured along the length of the modules. When operated in vertical position the required temperature homogeneity of +/- 2 °C was reached for several hours over the largest part (upper 4.5 m) of the modules. The observed larger temperature difference in the lower part of the modules (lowest 50 cm) is explained with bad thermal insulation of the mockup to the ground floor.

The operation of the blankets with only 3 (2) independent heating areas has also been tested and has resulted in a similar temperature homogeneity.

The handling of the prototype blankets in particular the mounting on the real stereo-layers has been tested with the C frames at Point 8.

The results reported in this note essentially fulfill the design requirements for the heating of complete stereo-layers. Slight modifications of the design are proposed to improve certain weaknesses observed during the tests.

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1 Introduction

Several methods to improve the aging behaviour of the LHCb Outer Tracker modules have been explored. In one of the methods the detector modules are warmed up to a temperature of 40 °C and are kept at this temperature for about 10 days while constantly being flushed with gas (gas-flow of 1 vol/h). To apply this procedure to the detector modules already installed at Point 8, it was proposed to enclose the individual C frames with large electric blankets. For practical reasons, always 4 single blankets, each with a height of 6 m and a width of 1 m, connected with velcro fastenings are used to heat one side of a C frame. Two of these 6×4 m^2 entities will enclose the C frame from both sides.

Two prototype blankets with an heating area of 5×0.85 m^2 have been built[1]. Tests to study the temperature steering and the homogeneity have been performed using a mini C-frame of four modules. After the temperature study, the mounting of the blankets to the Outer Tracker C frames was tried at Point 8.

2 Electrical Blanket

The layout of a prototype blanket is sketched in Fig. 1. The blankets have an overall length of about 6 m and a width of 1 m. The part equipped with electrical heating is smaller (5 m $\times$ 0.85 m) and subdivided into 4 electrically independent areas.

The blankets have an inner side, where the supporting glass fiber tissue is aluminized and is in direct contact with the electrical heating. Between the outer glass fiber tissue and the electrical heating a thin insulation layer (5 mm) should limit the heat loss to the outside.

Each heating zone (1.25 m $\times$ 0.85 m) provides a heating power of about 300 W. A single PT100 temperature sensor mounted on the heating wire measures the temperature and is used to control the corresponding heating zone. For temperature regulation of each area a commercial 2-point regulation[2] has been used.

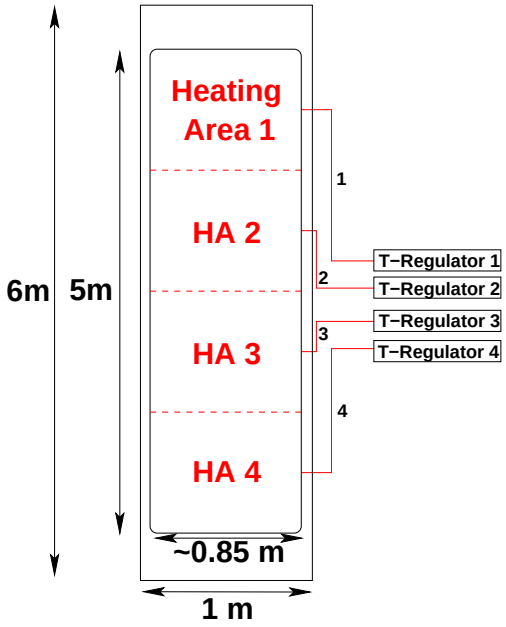

Figure 1: *Schematic view of a heating blanket. The label 'HA' stands for 'heating area'.*

The upper and lower passive parts (50 cm) of the blankets allow to mount the blankest on the C-frame and provide a closure of the heating envelope. A prototype blanket has a total weight of 17 kg.

[1] www.winkler-waerme.de/index_eng.htm
[2] www.brodersen.de/mxt-10.eng.pdf

3 Measurement of the Temperature Homogeneity

For the warm-up procedure it is important that the temperature inside the complete enclosed C-frame is around the required 40 °C. Higher temperatures can lead to damages, lower temperatures might not be as effective.

The quality of the regulation system and the temperature homogeneity was therefore studied in a first test (”Horizontal Test”), shown in Fig. 2, in which 2×2 Outer Tracker modules were placed on top of a first blanket and then were covered with the second blanket. The temperature profile along the modules have been measured.
In a second test (”Vertical Test”) a mini C-frame was used to place the modules vertically. This test aimed to study the effect of possible convection in the air gap between the modules of the two different stereo-layers. Naively one would expect a higher temperature on the top. The test should show if this effect is present and can be handled with the individual heating zone.

Figure 2: *Horizontal setup.*

To get a detailed picture of the temperature profile a 32 channel temperature system was developed. The system uses active temperature sensors[3] and a FPGA[4] to readout the sensors. A USB interface[5] provides computer connection.

3.1 Horizontal Test

In the first test, 2 modules were placed on top of the first electrical blanket which was lying with its insulated side on the floor. The second set of 2 modules was placed with distance holders above the first 2 modules and was covered with the second blanket. The distance between the 2 layers of modules was 2.5 cm. Temperature sensors were placed along the length of the modules in the air gap between the two module layers (called ”module-module” in Fig. 4) and between modules and upper blanket (called ”module-blanket” in Fig. 4).

Before starting the heating the blankets envelope was closed using the velcro fastenings at the sides and the ends of the blankets. The setup was slowly warmed up to 40 °C.

Fig. 3 shows the temperatures of the 7 sensors placed in the air gap between the two layers after reaching thermal equilibrium. The temperatures are very stable and all lie inside a ±2 °C band around the nominal value of 40 °C. The temperature measured on the outside surface of the blankets at thermal equilibrium was 26 °C.

Fig. 4 shows the time stability of the temperature measured between heating blanket and modules (black points) and inside the air gap between the two module layers (red points). The sensor between module and electrical heating show small wiggles which result from the switching of the heating.The switching is not seen in the temperature measured between the modules.

[3]SMARTEC temperature sensors: www.smartec.nl
[4]Spartan FPGA from Xilinks: www.xilinx.com
[5]FTDI Chip: www.ftdichip.com

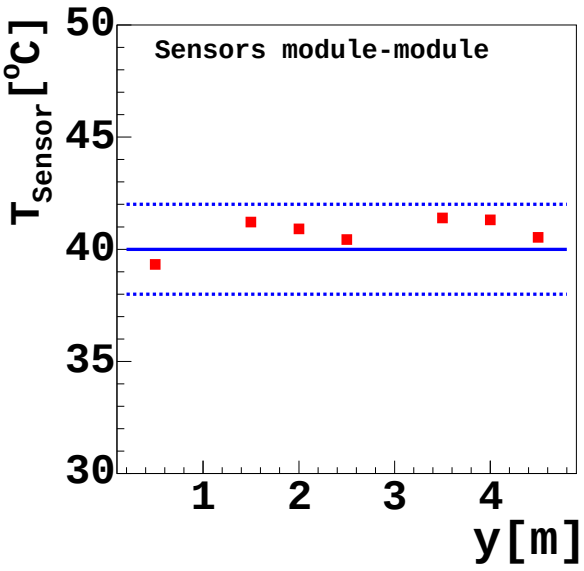

Figure 3: *Horizontal Test: Temperatures in the air gap between the modules after reaching thermal equilibrium. The x-axis gives the sensor position along the modules. All temperatures lie within the ±2 °C band around the nominal value of 40 °C.*

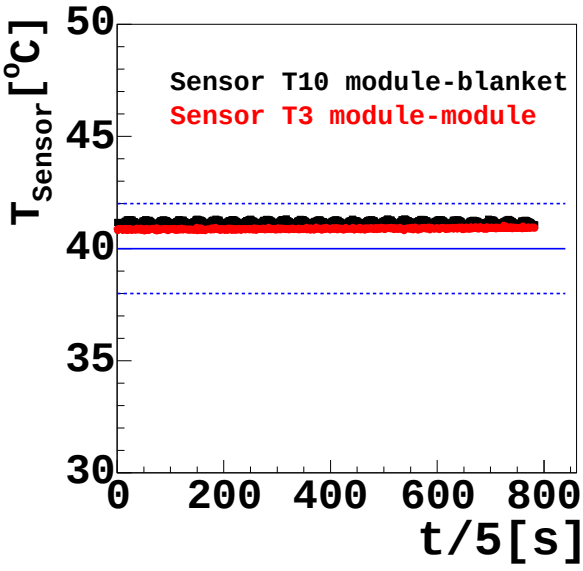

Figure 4: *Horizontal Test: Time stability of the temperatures. The black points show the time behavior of a sensor between blanket and module (y=3m), while the red points show the time behavior of a sensor in the air gap (y=2m).*

3.2 Vertical Test

For the vertical test a mini C-frame which consists out of two 6 m long aluminium bars and which can support 2 modules on each side was built. The setup is sketched in Fig. 5.

Fig. 6 shows the frame in vertical position with 2 modules mounted to it. The complete frame with 4 modules was enclosed with the two prototype blankets. The temperature sensors were placed according to Fig. 7. In addition temperature sensors have been put on the outside of the blankets, One sensor was also put inside a module to monitor its temperature. The temperature of the electrical blanket was raised slowly to the nominal value of 40 °C. The temperature profile was recorded after the system reached thermal equilibrium.

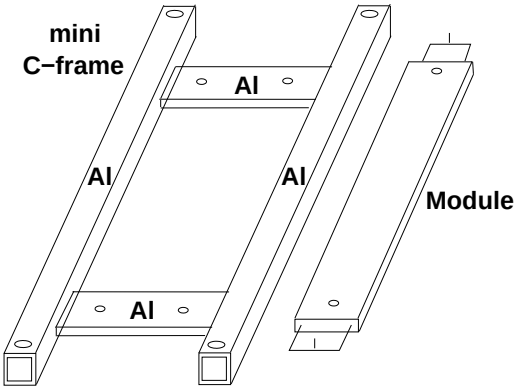

Figure 5: *Schematic view of the mini C-frame.*

Figure 6: *The mini C-frame with two modules.*

Fig. 8 shows, along the length of modules, the temperatures measured by the sensors between modules and electrical blankets (sensors T15...T18). The time stability of the same sensors is shown in Fig. 9. Similar behavior was observed for the sensors T19, T20, T21 and T24.

More critical is the temperature profile along the air gap between the two module layers. Fig. 10 and Fig. 11 show the profile along the vertical gap and the time stability of the temperatures.

While the temperature for the sensors T2...T8 are inside the accepted ± 2 °C band around the nominal value, the temperature at position T1 (sensor at the lower end of the mini C frame) is with T = 33.5 °C significantly lower.

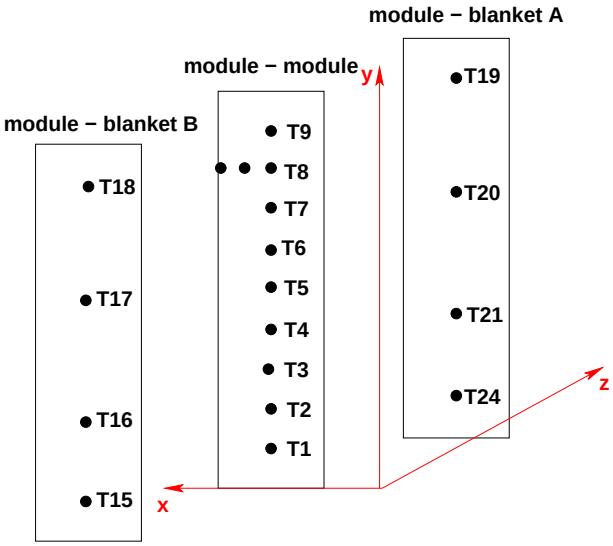

Figure 7: *Temperature sensors setup.*

As the closure of the blankets at the lower end was not perfect additional insulation was installed (the lower end was wrapped with air cushion foil). The temperature of T1 increased to 36 °C.

The remaining temperature difference clearly points to a heat sink at the lower end. As the two aluminium profiles of the mini frame are in direct contact with the floor and it is expected that at the lower end heat will flow via the aluminium bars into the floor.

By putting the lower heating area at a nominal temperature of 45 °C a temperature of 38 °C was reached at the position of T1. The sensor T2 (at 1m height) showed a temperature of 43 °C. The temperature between blankets and modules increased - as expected - to 45 °C for this section of the blanket.

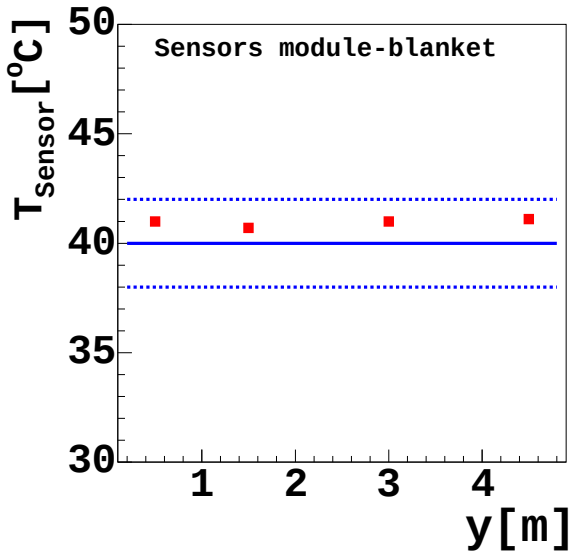

Figure 8: *Space T-profile in first test between modules and blanket.*

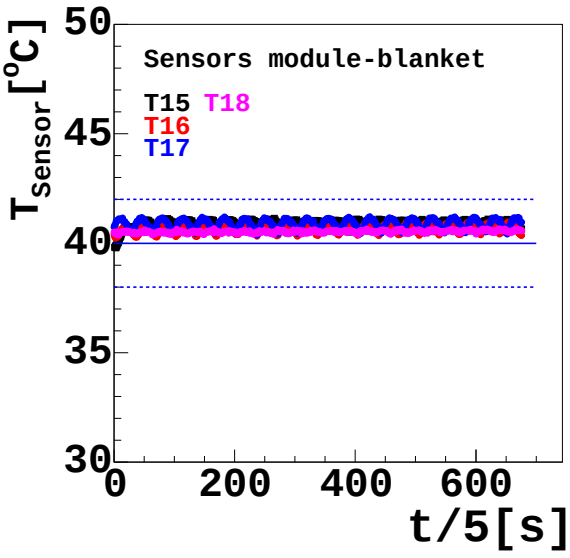

Figure 9: *Time T-profile in first test between modules and blanket.*

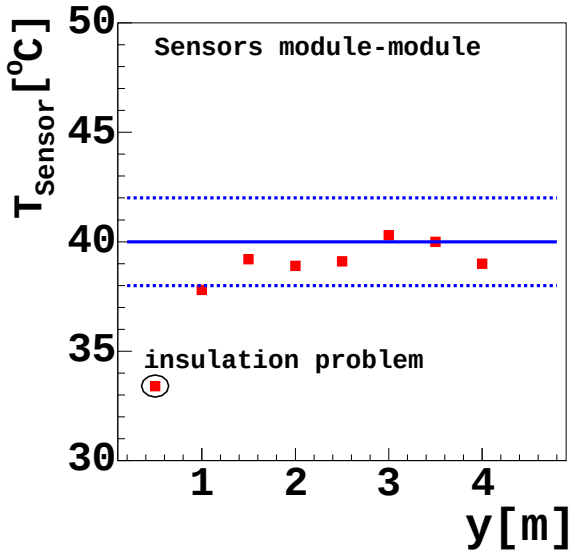

Figure 10: *The T-profile along the vertical gap between the two rows of modules.*

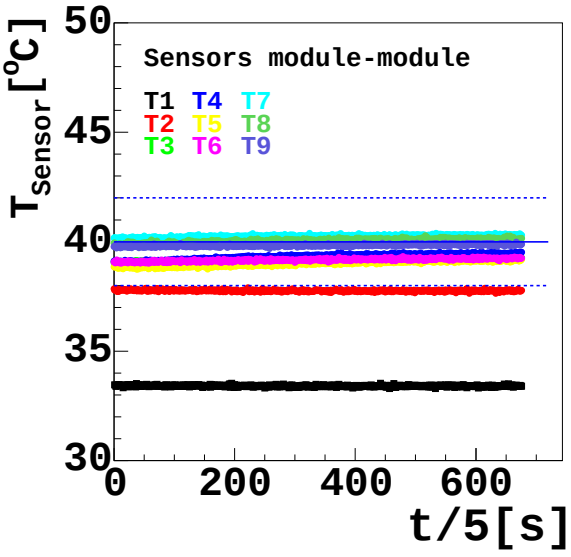

Figure 11: *Time stability of the temperatures between the two rows of modules.*

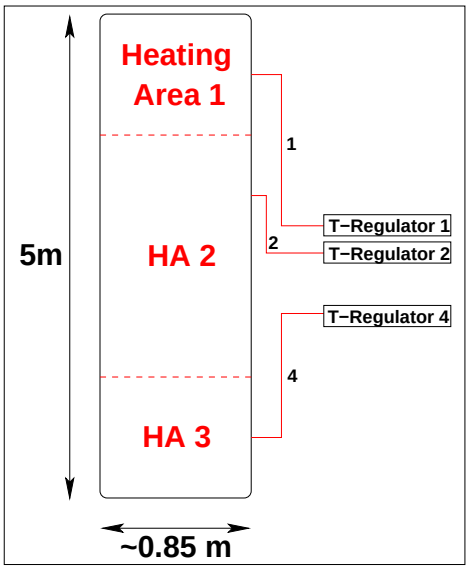

Figure 12: *Schematic view of heating blanket steered with three heating areas.*

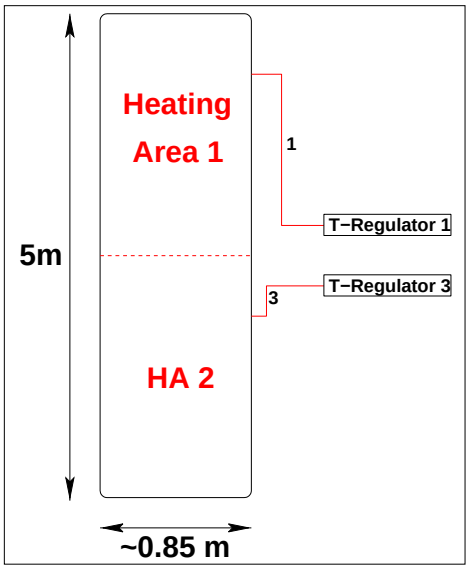

Figure 13: *Schematic view of heating blanket steered with two heating areas.*

In the last two tests the number of independent heating areas was reduced:

- The inner two heating areas were coupled according to Fig. 12 The temperatures profile measured in between the module layers along the length of the modules are shown in Fig. 14. The temperature of the enlarged heating zone in the center are inside the ± 2 °C error band.
- The independent heating areas were reduced to two according to Fig. 13. As the temperature of the lowest sector is now controlled by a sensor which is more than 1.5 m away from the ”cold” end of the blanket the temperature of this part (sensor T1) dropped further. For the upper area all temperatures are again inside the ± 2 °C error band, see Fig. 15.

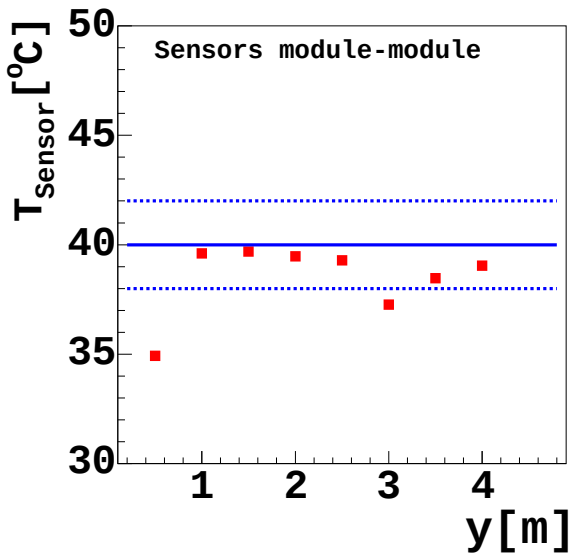

Figure 14: *The T-profile along the vertical gap between the two rows of modules for a heating blanket steered with* ***three heating areas****.*

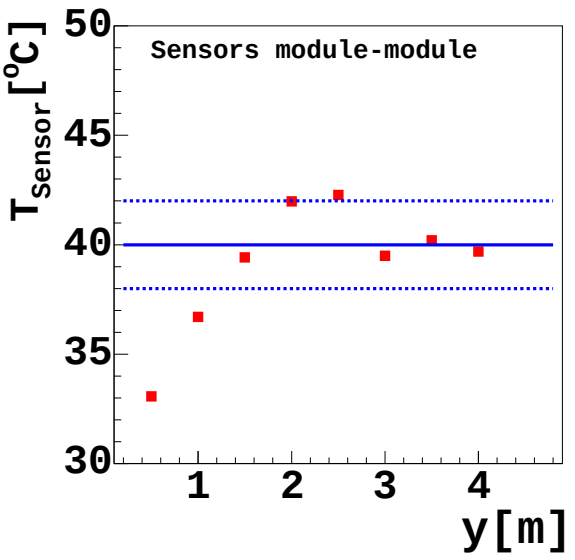

Figure 15: *The T-profile along the vertical gap between the two rows of modules for a heating blanket steered with* ***two heating areas****.*

4 Mounting tests at Point 8

The mounting of the two prototypes blankets on the C frames has been tested at Point 8. Hooks which were put on the upper arm of the C frame were used to sustaine the blankets, see Fig. 16. It was not possible to put this simple fixation at the position of the C frame supports. In future a different solutions has to be found here.

Figure 16: *Installation of the heating blanket in Point 8.*

After installtion the blankets were hanging straight but they were not always touching the modules. In the center of the stereolayer the distance between modules and blankets was up to 2 cm. While this should not cause problems for the heating it will prevent the movements of C frames when being enclosed with electrical blankets.

5 Revised design of the heating blankets

A a result of the heating tests a rearrangement of the heating sectors is proposed: smaller sectors, only about 50 cm long, at both ends of the blankets should account for possible heat sinks from the C frames. The two heating sectors in the center of the blankets should be a little longer (about 2 m) to avoid an increase of the number of sectors per blanket. A sketch of the revised design is shown in Fig. 17.

With respect to the protoype the heating zone should be enlarged to reach over the ends of the modules. On each end 8 cm will be added to the heating areas.

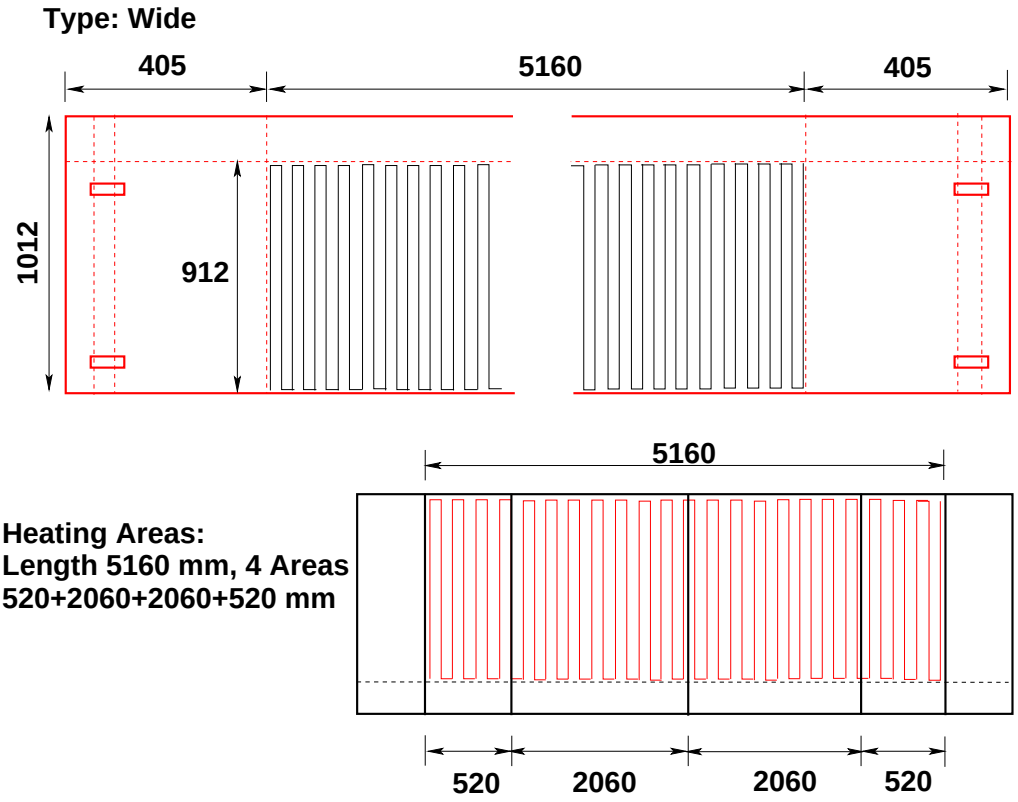

Figure 17: *Schematic view of the revised design of the heating blanket.*

6 Conclusions

Heating blanket prototypes with four independent heating areas have been tested. The temperature profiles of the blankets show the necessary uniformity in space and time for the horizontal tests performed. The time stability has been observed also in the vertical tests.

The temperature profile along the modules in the vertical tests showed a drop at the lower ”cold” end of the setup. To compensate possible heat sinks at the top and bottom of the C frames the final design of the electrical blankets was modified and small heating sectors at the ends have been introduced.