VLPC Temperature Control Hardware

1 Overview

The VLPC system for the DØ central tracker upgrade will consist of 80 cassettes. Each cassette has 1024 VLPC channels, in 8 modules per cassette, 16 chips à 8 VLPC pixels per module. Each module has a heater/sensor card (HSC) [drawing number 3823.113-MB-317558] containing one temperature sensor and 2 heaters mounted on the bottom of the isotherm [part number MB-317278]. Electrical connections to the HSC are made via a flex cable and an eight-pin cin::apse connector [drawing number 3823.113-MB-317274]. All the modules in a cassette will be thermally coupled, and in standard operation mode it is intended to use only one temperature sensor per cassette to control all the heaters in that cassette.

The sensor and heater lines will be routed through the righthand front-end electronic boards to the backplane, from were they will be transmitted through appropriately shielded cables to the control system. Industrial PID controllers will be used. Several systems have been successfully tested (Anafaze 8LS in the 3000 channel test: needed modified (linear) power supply to reduce electrical noise; GE-FANUC series 90-30 in R2D1 test stand) for compliance with electrical noise and temperature stability requirements, and more tests are planned (TI-SIEMENS with FIX-DMACS). It is intended to integrate the temperature control and monitoring of the VLPC system into the overall DØ cryogenics control using FIX-DMACS.

(**August 1998: After tests with the DØ standard TI-Siemens system showed high noise levels, an alternative solution using an on-board microcontroller is being investigated.**)

2 The Heater/Sensor Card (HSC)

2.1 Properties of Temperature Sensors and Heaters

2.1.1 The Sensor

The sensor used is a standard 1/8 Watt carbon film resistor [e.g. Allen-Bradley, FNAL stock number 1487-0265] with a nominal resistance of 100 Ohm at room temperature. Its resistance is inversely proportional to temperature; at 6.5 Kelvin, these resistors have a resistance of $\sim$ 500 Ohm, and a sensitivity of $\sim$ 100 Ohm per Kelvin; at 10

Kelvin the resistance is $\sim$ 300 Ohm, and the sensitivity is $\sim$ 29 Ohm per Kelvin. The resistors are mounted on the HSC (see below) and then calibrated at Fermilab. The precision of the calibration is better than 1 Millikelvin = 0.1 Ohm at 6.5 K.

2.1.2 The Heater

The heater resistors are standard metal film resistors of 500 Ohm nominal value, 1/8 Watt, which exhibit a resistance of 500 Ohm also in the operating temperature range.

3 TC components on the CFT Front-end Board

For each module four sensor lines (two pairs) and four heater lines (two pairs) are brought to the righthand FE board via the flex circuits. In the baseline design eight of the sixteen heater resistors, one from each module, are selected and series-connected via jumpers on the FE board to form a single heater chain. Jumpers or a front-panel switch (preferred) are used to select one of the eight temperature sensors. The four lines for this sensor and the two heater chain terminals are routed through a filtering network to the backplane. On the backplane the temperature control lines for eight cassettes are gathered into a 50 pin connector, for export to the external PID controller via a (shielded) twisted pair cable.

3.1 Signal levels on the TC lines

In the baseline design TI/Siemens RTD modules specifically modified for DØ are used to drive and read out the sensor resistors. The drive current is 10 μA, which yields a signal level of between 1 mV and 12 mV, typically 5 mV. The overall error on the temperature measurement and control is to be kept below 0.1 K, ideally around 10 mK. Thus an electrical precision of 1 per mille should be aimed for. In the baseline design, this translates into current errors and noise of not more than 10 nA, and voltage offsets and noise of not more than 5 μV.

For comparison: for the 3000 channel cosmic ray test, a system using external PID controllers with 60 μA drive current (and corresponding signal level of 6 mV to 60 mV) through individually shielded twisted pair cables had been successfully employed.

3.2 Alternative Design: PID Controller on FE Board

If sufficient noise suppression can not be achieved with the (TI/Siemens) baseline design, on-board closed-loop temperature control is the most attractive alternative. (Other industrial controller options have been successfully tested, but are more expensive and offer less features then the onboard option.) Such a design can now be realized with very few components, and suitable chips have been identified. 50 μA current source chips have already been tested, and are on the current stereo prototype board for all eight sensors. One or more of the sensor voltage pairs would be routed through an op-amp with sufficiently low input current and offset voltage and appropriate gain (e.g. A/D OP-97) to the analog input(s) of a microcontroller with built-in ADC (e.g. PIC14000). The heater chain would be driven by a D/A converter connected to the digital output of the microcontroller. Control parameters would be downloaded through the standard MIL1553 FE board interface.

Using an onboard microcontroller with multiple analog inputs has the added advantage (besides lower noise pickup susceptibility and lower per-loop cost) that temperature monitoring and averaging over all eight modules can be easily implemented, and that error modes as e.g. a failure of one or more sensors can be dealt with in a straightforward fashion in the microcode of the controller.

4 Test Results for the HSC

Tests were performed on 10/9/95, 10/10/95 and 10/13/95, in the single cassette test stand R2D1 in DAB.

A prototype copper isotherm was tested, equipped with a prototype heater/sensor card on the bottom, and additional temperature sensors mounted on VLPC substrates on the top side of the isotherm. The isotherm itself was mounted standing on one of its short sides, i.e. in a position rotated by 90 degrees with respect to operation in the 1024 channel cassette. Thus any contribution to heat conduction due to convection was not modelled correctly in this test.

For 200 mW heater power applied to a resistor in the HSC a temperature increase of 1.5 to 1.8 K was observed, as measured on the heater/sensor card. The temperature as measured by the top sensors was lower by 0.0012 K/mW (resulting in 0.24 K difference for 200 mW heater power) than the temperature measured on the sensor board. It is believed (from finite element calculations for a model) that this temperature differential is due to heat conduction through the G10. The model predicts that the temperature differences across the isotherm itself are smaller than 1 millikelvin, for a copper isotherm; thus for the final modules an aluminum isotherm can be afforded and has been specified. In accordance with this prediction, no differences larger than

0.01-0.03 K between top sensors (in the VLPC positions) were observed, independent of the HSC power applied. When one of the front sensors was heated (1-2 mW power), no effect was observed in any of the other sensors (top and bottom). The heated sensor itself showed a very large temperature differential of 1.5 K/mW.

Conclusions:
1) If we intend to keep the total heater power per cassette below 200 mW, none of the cassette temperatures can differ by more than 0.2 K from the baseline 'cryostat temperature' (actually, the cassette temperature without heater). This has implications for the required cryostat performance (temperature homogenity), and for the VLPC operating points matching. In the 3000 channel system test, we ran all channels at the same temperature, with more than reasonable performance. From the HISTE VI calibration performed in November 1996 it is expected that the new VLPC generation will also have a narrow distribution of the optimum operating point.

2) The temperature difference VLPC position - heater/sensor board is a nuisance. For 25 mW per module it amounts to 0.025 K, and is thus de facto negligible. For 200 mW per module it is not, but since all the top sensors tracked identically in the test, this effect could be calibrated out. Better thermal coupling bottom sensor - isotherm and heater - isotherm would help, as would less heat conduction through the G10 (unfortunately a thinner board is not a viable solution, as this would complicate the mounting of the HSC in the calibration fixture). But as stated before, other consequences of having to apply 200 mW per module are more severe (helium consumption). An additional 0.8 W per cassette (from 100 mW average per module) increases Helium consumption by almost 50 %.

3) The heat flow into the VLPC substrates is critical: the heat conducted down the flex circuit can not be allowed to flow through the VLPC substrates, but has to be shunted directly to the isotherm through the stainless steel clamping bars [part number MB-317272].

Further tests have to be done when the prototype 1024 channel cassette and the test cryostat are available (module to module differences; cassette location dependence).

4.1 Manufacture of the Heater/Sensor Card (HSC)

The HSC [drawing number 3823.113-MB-317558] is mounted to the bottom of the isotherm [part number MB-317278] by means of two machine screws [binder head screw 2-56 x 1", stainless steel], one of which also serves to hold the eight-pin cin::apse connector [drawing number 3823.113-MB-317274] on the bottom side of the HSC. Electrical connections are made via the 'dog leg' of the 'right hand side' flex circuit.

Soldered to the top side of the HSC (the side with the large copper pads for improved thermal contact to the isotherm) are two 500 Ohm 1/8 Watt metal film resistors, and one 100 Ohm 1/8 Watt Allen-Bradley carbon film resistor as sensor. The sensor is mounted in the middle position. (Obsolete: *Whereas the heater resistors on the left and right edge of the HSC are soldered with their leads directly into the board, the sensor has its leads replaced by thin copper wire [gauge 40], to reduce thermal stress on the resistor itself. The original leads are trimmed to $\sim$ 2/10 of an inch each, and the thin wires are soldered into the HSC holes. Care should be taken to tin only as much as necessary of the thin wire, so that it stays flexible.*) All three resistors are to be mounted flush to the HSC in such a way that they fit into the cutouts (slots) made for this purpose in the bottom of the aluminum isotherm.

Unique ID numbers are assigned to the HSCs in the calibration step.

4.1.1 Steps of HSC Manufacture, 1.: Resistor Mounting

August 1998: HSC production has finished (for quite a while already). The original procedure was not followed. Thermal cycling will have to be done prior to calibration, using a simplified procedure.

1. The 500 Ohm heater resistors are prepared for mounting, by bending the leads at the appropriate distance (distance of the mounting holes in the HSC).
2. The two heater resistors are soldered into the left and right position on the top side (large copper pad side) of the HSC.
3. The heater leads are trimmed.
4. **modified sensor mounting procedure: The sensor is inserted and its leads are soldered directly to the PC board, following the same procedure as for the heater resistors.**
5. *the following steps are obsolete:*
   (a) *The sensor is prepared: a few turns of thin copper wire [gauge 40] are wound around the leads on each end, as close to the body of the 100 Ohm resistor as possible.*
   (b) *The thin wire is soldered to the old leads, without tinning more than necessary of the new lead.*
   (c) *The new wires are trimmed to $\sim$ 1 inch length on each end.*
   (d) *The old leads are trimmed off as short as possible.*
   (e) *The thin wires are inserted into the sensor mounting holes of the HSC, and soldered in. The thin wire leads should not be under tension.*
   (f) *The thin wire leads are trimmed on the bottom of the HSC.*

6. *The leads and the top side copper pads connected to the resistors are varnished or covered with a thin (1 mil/ 2 mil?) kapton tape in those areas around the mounting holes where the solder resist coating has been removed or damaged.*

4.1.2 Steps of HSC Manufacture, 2.: Preparation for Calibration

August 1998: Thermal cycling has not been done. A simplified version of this procedure (bulk dunking, single warm measurement) will be executed just before the calibration.

1. The HSC is cycled five (5) times from room temperature to 77 Kelvin (liquid nitrogen) and back; i.e. the whole board is dipped for a few seconds into a container with liquid nitrogen, then removed, and brought again to room temperature.
2. The test leads of an Ohm meter are attached to two of the edge contact pads, so that the sensor resistance can be measured.
3. The resistance at room temperature is written down, to 1/100th of an Ohm.
4. The HSC is dipped into liquid nitrogen, and after reaching thermal equilibrium the cold resistance is logged.
5. The HSC is removed from the liquid nitrogen, and warmed up. The warm resistance is logged again.
6. The last three steps are repeated (at least once) until the cold and warm readings are stable to within 15/100th of an Ohm. If stability can't be achieved, the HSC is discarded. (Ken Gray is familiar with the exact acceptance criteria.)
7. The HSC is ready for calibration ($\rightarrow$ Mark Rushman).

4.1.3 Steps of HSC Manufacture, 3.: Calibration

August 1998: The number of calibration points has been changed. Mark Rushman is not at FNAL anymore.

(suggested) Calibration points:

1. From 4.2 K to 15 K: every 0.2 K.
2. From 15 K to 20 K: one point per Kelvin.
3. One point at 77 K, or some other intermediate temperature.

4. One point at room temperature.

HSCs are labelled with the unique sensor calibration identifier assigned by Mark Rushman. The sensor calibration ID should be marked indelibly on the bottom side (opposite the resistors) of the HSC, and (obviously) not on the break-away connector part.

4.1.4 Steps of HSC Manufacture, 4.: Mounting on the Isotherm

Most of the mounting procedure is described in the section 'Final Module Assembly Procedure' ($\rightarrow$ Carl Lindenmeyer).

1. The HSC extension used for insertion into the calibration device has to be broken or cut off. Make sure the copper traces are not shorted at the edge where the extension is removed.
2. If the HSC sensor ID has been marked on the top side, copy the number to the bottom into an area which will still be readable when the HSC is mounted.
3. Fill the resistor cutouts (slots) in the bottom of the isotherm with vacuum grease (electrically non-conductive grease serving as thermal couplant).
4. Align the HSC, resistor side towards the isotherm, cin::apse contact pattern towards you (i.e. opposite the end of the isotherm which has the two tapped holes used for clamping the isotherm to the assembly fixture), with the isotherm, and push the resistors into the grease beds. Follow the steps outlined in the 'Final Module Assembly Procedure'.
5. When preparing and mounting the 8-pin cin::apse connector [part number MB-317274], do not touch or wipe the two contact surfaces.

4.1.5 Steps of HSC Manufacture, 5.: Final Checks

1. The label identifying the HSC (the sensor calibration ID number) is readable with the HSC mounted to the isotherm.
2. The heater resistors measure $\sim$ 500 Ohm.
3. The sensor resistor should read $\sim$ 100 Ohm.
4. All other trace combinations should read infinity (a MOhm reading).
5. All resistors should be electrically isolated from the isotherm, as measured e.g. against the screws holding the HSC (i.e. use a non-anodized spot on the isotherm to make contact for this measurement).