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Multichannel Temperature Regulator for SIS100 HTS Current Leads

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ABSTRACT

In GSI for SIS100 accelerator about 530 HTS Local Current Leads 250 A must be produced for superconducting corrector magnets. To provide a high voltage electrical insulation, the top warm terminals must be kept at a temperature of 25 °C, using screwed cartridge heaters. Known industrial cartridge heaters don't meet insulation specification at 1100 V. All tested temperature regulators on the free market failed during the tests at GSI or/and produced significant electrical noise. With the specifications from GSI we developed and manufactured 8 channel temperature regulators for the SIS100 HTS current leads which were successfully tested and with low noise. GSI and ILK also developed reliable cartridge heater with high voltage insulation and imbedded temperature sensor. Design issues and test data are presented in this paper.

Keywords: temperature regulation, heater cartridge, current leads, electronics

1. INTRODUCTION

Current leads terminals need heating to ensure that the cold from the cryostat is not leading to condensation. For the SIS100 accelerator about 530 **H**igh **T**emperature **S**uperconductor (HTS) **L**ocal **C**urrent **L**eads (LCL) for 250 A are needed. Each terminal has a 35 mm² copper lead to the 50 K level [1] and requires heating in the range of 7 W, with security 15 W. We have developed an 8-channel temperature controller that meets the specifications from GSI:

- 24 V DC supply, 8 independent channels, 15 W per channel,
- 1100 V electromagnetic interference resistance
- Low electromagnetic noise
- 4-wire Pt1000 temperature sensor input with failure detection
- Measurement of heater resistance and power (detection of failure)
- Automatic redundancy (if one channel fails, a second takes over)
- Status reporting
- Compactness and low costs

The temperature controller is planned to be used at several points of the SIS100 magnet system. Each corrector magnet has two (sextupole) or four (steerer) LCL terminals with two heater cartridges each for redundancy. One controller would be sufficient for tempering one steerer or two sextupole magnet LCLs. For higher redundancy which also covers power supply and controllers, it would be necessary to use two different controllers and supplies for each of the cartridges pairs.

2. DESIGN AND DEVELOPMENT

The temperature controller is designed to control up to eight heater cartridges (see figure 1). One micro controller with 8 **P**ulse **W**idth **M**odulation (PWM) outputs is used to control 8 output power drivers with a frequency of 100 kHz at 24 V. Each of the drivers is capable of driving 1.5 A and has an internal fault detection that reports back to the micro controller. After the driver a high efficiency coil-capacitor-filter is applied, which reduces ripple below 10 mV. The output of the heater interface uses the filtered voltage and one shunt resistor to ground for current sensing. The voltage taps from the shunt resistor and the heater are equipped with surge suppressing resistors and diodes before the sensor multiplexer. This ensures robustness against electromagnetic interference, short circuit or external surge voltages.

The required precision for temperature measurements is in the range of uncalibrated class B Pt1000 sensors. In this range there are no special requirements as for cryogenic sensors would be [2] and it can be realized as a simple 0.1 % tolerance resistor divider. The voltage taps of this divider are also equipped with surge resistors and diodes to achieve the electromagnetic interference robustness. All sensors are fed to the same differential multiplexer with differential 0.1 % tolerance gain stage and the internal **A**nalogue to **D**igital **C**onverter (ADC) of the micro-controller. The temperature is calculated from this ADC value with a 5th order polynomial. Also the resistance and the power of the heater are calculated.

Each heater channel has its own **P**roportional, **I**ntegral and **D**ifferential (PID) regulator. All parameters and desired temperatures are pre-defined and can be changed individually or for all channels together. It is also possible to en- and disable each channel. All channels and sensors are monitored with configurable warning and error limits. Depending on the setting, an error or a warning will trigger an external signal. The micro controller has a RS485 data interface for transferring settings, sensor values and all other data to and from a **P**rogrammable **L**ogic **C**ontroller (PLC) or a **P**ersonal **C**omputer (PC). It is also planned to equip the temperature controller with a small display and input keys for direct control.

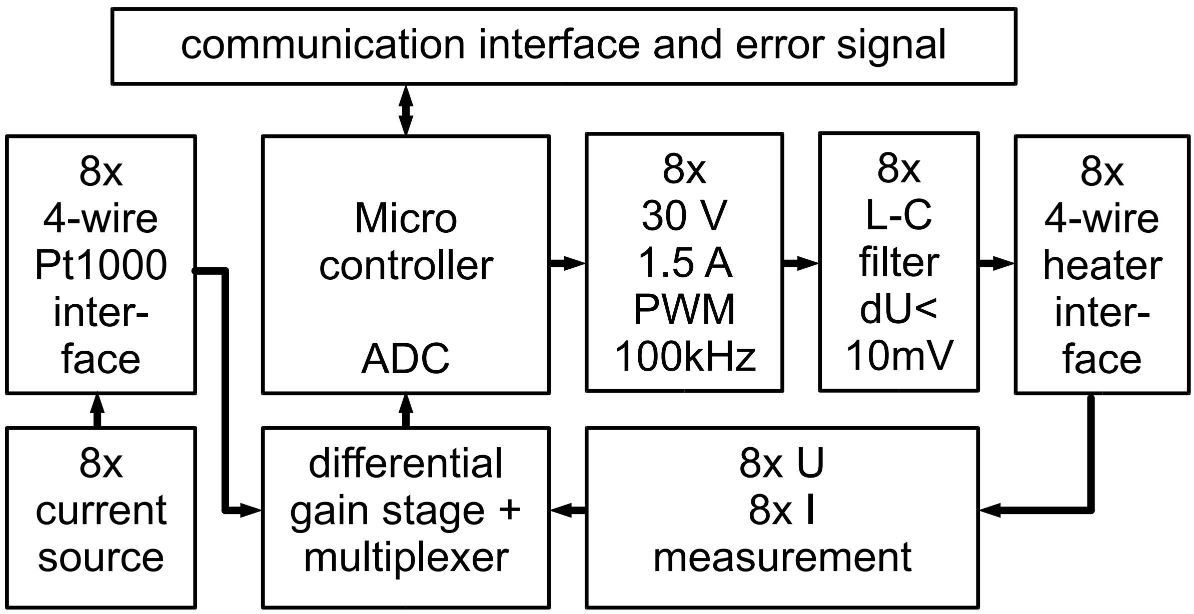

Figure 1: Hardware scheme for 8 channel temperature controller

3. RESULTS

A first prototype (figure 2) has been built and was delivered to GSI. All connectors for heaters and sensors are designed in 4-wire technology. The heater cartridges (figure 4) with included temperature sensor are connected in 2-wire technology with approximately 2 m cable length. The board is directly connected to a 24 V power supply and a RS485-USB converter with a control PC. The control program is directly accessing the micro controller for reading and setting of data. It shows all values of the sensors and the setting of heater outputs and regulators. All values can also be displayed a time-graph and be recorded in a data file.

For a good regulation characteristic all regulation parameters have to be adapted to the used heater cartridges and the attached structure of current lead terminal. Figure shows the temperatures (T1 – T3) of three heater cartridges terminals during dT = 1 K jump of set the set temperature (T set). All temperatures of the mounted heater cartridges follow this jump with a settling time of approximately 200 s with low overshooting. This first measurement also shows that the temperature measurement has some systematic noise behaviour. This is most probably caused by insufficient decoupling of ground paths between power driver and measurement electronics. This feature will be improved with the next version.

During the first measurements at GSI, several possibilities for distortions have been tested and the behaviour of the temperature regulator has been observed. Those test included jumps of the regulator set value (figure 3), unmounting and mounting of heater cartridges during operation, redundancy check by detaching of cartridges and long term stability (more than 3 days). All tests were successful and the temperature controller did show the expected behaviour:

- Raise of set value → temperature was rising accordingly with 10 % overshoot
- Unmounting/mounting of cartridge → decrease/increase of heat load
- Detaching of cartridge → secondary cartridge takes heat load of first cartridge
- Long time stability → temperature stays stable and heat load changes according to day and night time (ambient temperature change)

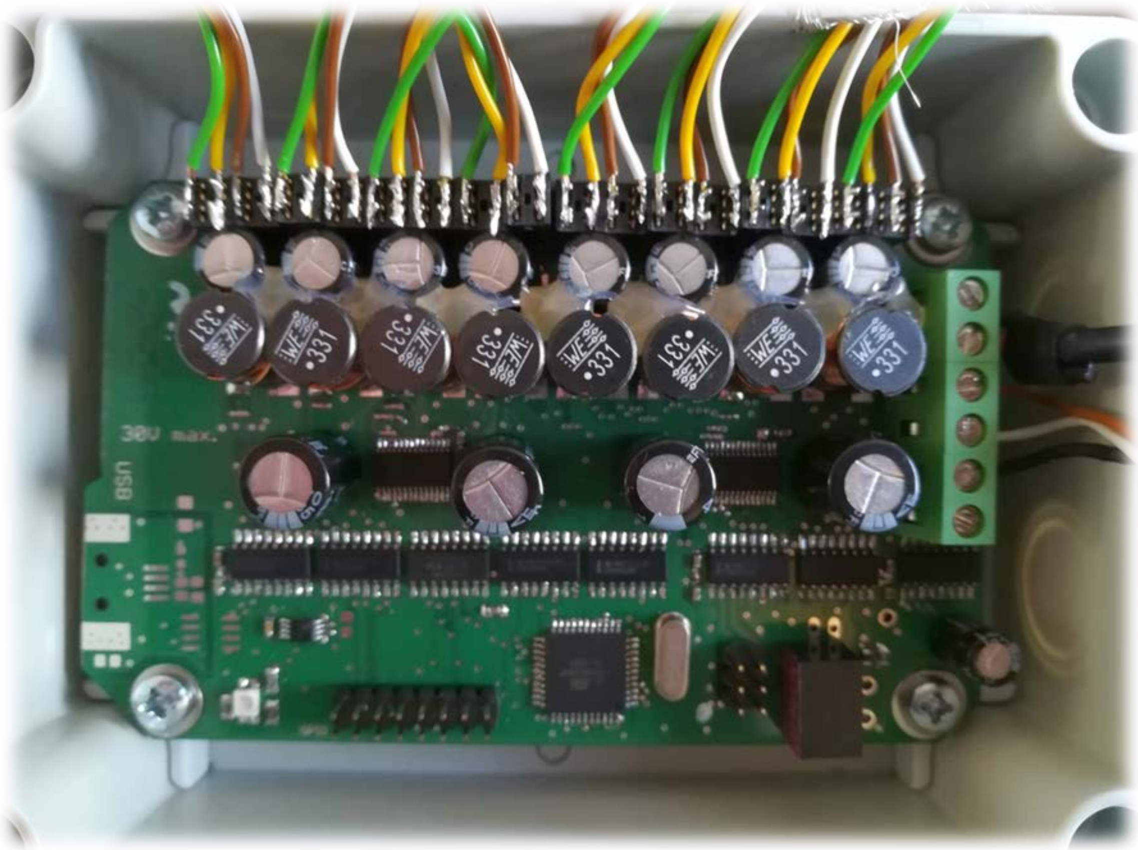

Figure 2: First prototype temperature controller for 8 independent channels

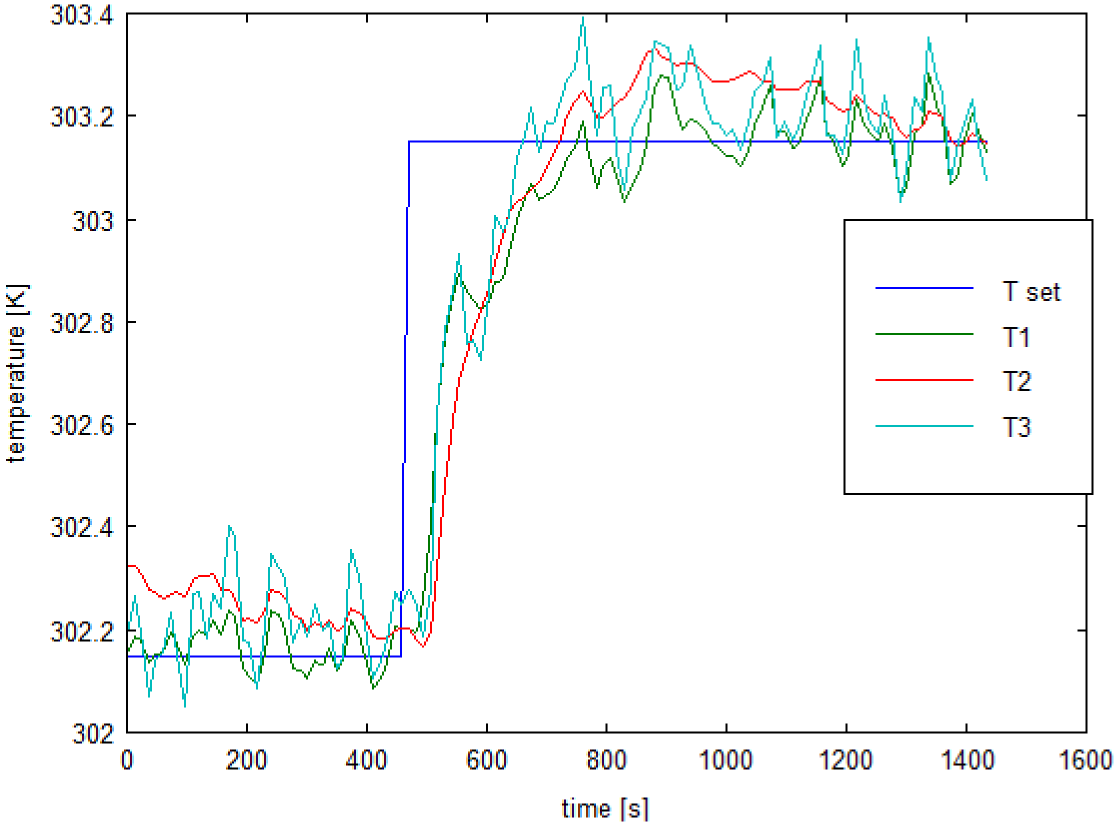

Figure 3: Measured signals at a set-value (T set) jump

Figure 4: Heater cartridges with included Pt1000 temperature sensor

4. CONCLUSIONS

We developed an 8-channel temperature controller for driving 8 independent heaters with one temperature sensor per channel. It has a very compact design of 12 cm x 7 cm x 2 cm, high electromagnetic interference resistance, low noise outputs, high efficiency, fully controllable with a field bus, resistance monitoring and capable for fully redundancy. This initial prototype works already satisfying and meets the specifications from GSI. Some minor improvements should be done in the board layout to remove common ground paths with the measuring electronics. For the final devices for usage at GSI it is planned to have 19 inches slides for up to four 8-channel modules with display and setup keys.

NOMENCLATURE

I	current (A)	R	resistance (Ohm)
U	voltage (V)	P	power (W)
T	temperature (K)	t	time (s)

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