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Cryogenic Thermometer Calibration Facility at CERN

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Abstract

A cryogenic thermometer calibration facility has been designed and is being commissioned in preparation for the very stringent requirements on the temperature control of the LHC superconducting magnets. The temperature is traceable in the 1.5 to 30 K range to standards maintained in a national metrological laboratory by using a set of Rhodium-Iron temperature sensors of metrological quality. The calibration facility is designed for calibrating simultaneously 60 industrial cryogenic thermometers in the 1.5 K to 300 K temperature range, a thermometer being a device that includes both a temperature sensor and the wires heat-intercept. The thermometers can be calibrated in good and degraded vacuum or immersed in the surrounding fluid and at different Joule self-heating conditions that match those imposed by signal conditioners used in large cryogenic machinery. The calibration facility can be operated in an automatic mode and all the control and safety routines are handled by a Programmable Logic Controller (PLC). LabVIEW® is used both as the PLC operator interface and for configuring and reading the thermometric data sampled by the higher accuracy laboratory equipment. The isothermal support onto which the thermometers are mounted is thermally anchored through the wiring to a helium bath. The calibration procedure begins once the temperature of the support is stabilized. Measured data is presented and it is possible to infer that the absolute accuracy that can be obtained is better than ± 5 mK for the full temperature range.

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INTRODUCTION

The LHC project[1] will use about 1600 long superconducting magnets operating in pressurized liquid helium at 1.8 K and whose total cold length exceeds 25 km. The temperature of these magnets is a control parameter and as a consequence the cryogenic thermometers and their ancillary electronics are critical components that need to have adequate precision, redundancy and to be of industrial robustness; their total quantity is about 7000. This equipment will be installed inside the LEP tunnel, of 27 km circumference, and will be exposed to environmental conditions that are hostile from the point of view of ionizing radiation damage and electromagnetic interference.

The measurement of cryogenic temperatures is reputed to be difficult for various reasons like thermal anchoring of electrical leads, long-term stability of sensors, signal recovery and in the case of a particle accelerator, radiation hardness. The aimed accuracy is 0.25% of the measured temperature: this value is imposed on one hand by the maximum temperature at which the magnets can operate without losing the superconducting state and on the other hand by the cooling capacity of the cryogenic system[2]. In order to obtain such accuracy and a 20 year trouble-free operation, CERN has launched a program on cryogenic thermometry. This activity includes (a) the study of assembly techniques compatible with the factory floor[3], (b) design of calibration stations with high throughput, (c) procurement of temperature standards traceable to a national metrological laboratory, (d) sensor stability tests in existing machinery, (e) irradiation damage at low temperature, (f) creation of an Oracle® database for storing the sensor calibration data, making statistical analysis and studying long-term stability; and (g) selection of the most suitable sensor for the LHC project. This paper describes the calibration facility for cryogenic thermometers that satisfies the accuracy requirements of the LHC: it has the potential of processing about 240 thermometers per month, each batch being cycled and calibrated 3 times from ambient temperature down to 1.8 K.

At present the CERN temperature standard is maintained by comparing a set of secondary and working RhFe temperature standards; the apparatus for this purpose has been described elsewhere[4]. A primary temperature standard consisting of a neon triple point sealed cell is used to perform periodical checks on the secondary standards. The temperature is traceable in the 1.5 to 30 K range to the “Istituto di Metrologia G. Colonnetti”, Turin, Italy. High quality RhFe standards of different origin (H. Tinsley in the U.K. and VNIIFTRI in Russia) are used in order to detect drifts that could be produced by the fabrication technique.

APPARATUS

In order to get the best accuracy when installing a thermometer in the field, it is essential that its calibration be made in conditions as close as possible to those found in the cryogenic machinery. The main parameters are the thermometer’s environment (vacuum or immersed in a fluid) and the Joule self-heating imposed by the type of signal conditioners used. The Joule effect seems to be critical with modern thin-film type thermometers probably because the heat evacuated through the wire bonds is not as efficient as that occurring in bulk-type sensors (for example an Allen-Bradley type) that use much thicker wires. The thermal anchoring of the wires and sensor with the object being measured can be reproduced in the calibration bench when using a thermometric block with built-in heat interception[3].

Isothermal substrate and insert

An isothermal substrate (see Figure 1a) is used for comparing a set of industrial thermometers[3] with up to 5 working standards that are installed inside holes drilled at each end of the substrate; up to 60 thermometers can be calibrated simultaneously. The calibrations are done mostly under vacuum conditions by using a vacuum enclosure surrounding the substrate (Figure 1b). The vacuum tightness is obtained by using

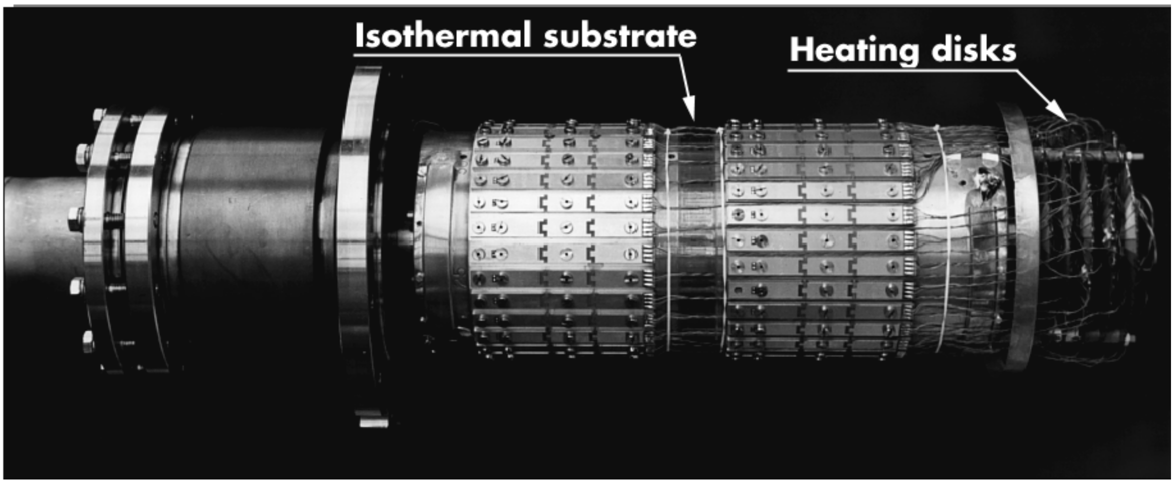
Helicoflex® metallic seals. The substrate is made of O.F.H.C. copper and its total mass is about 34 kg. The electrical connections are done by using manganin wire exclusively, there are 6 x 48-pin vacuum-tight connectors at room temperature and the wiring length is about 2 meters. The temperature of the substrate can be varied by either using an electrical heater or gaseous helium as heat exchange gas with the surrounding media.

The wires are thermally anchored at two different temperatures:

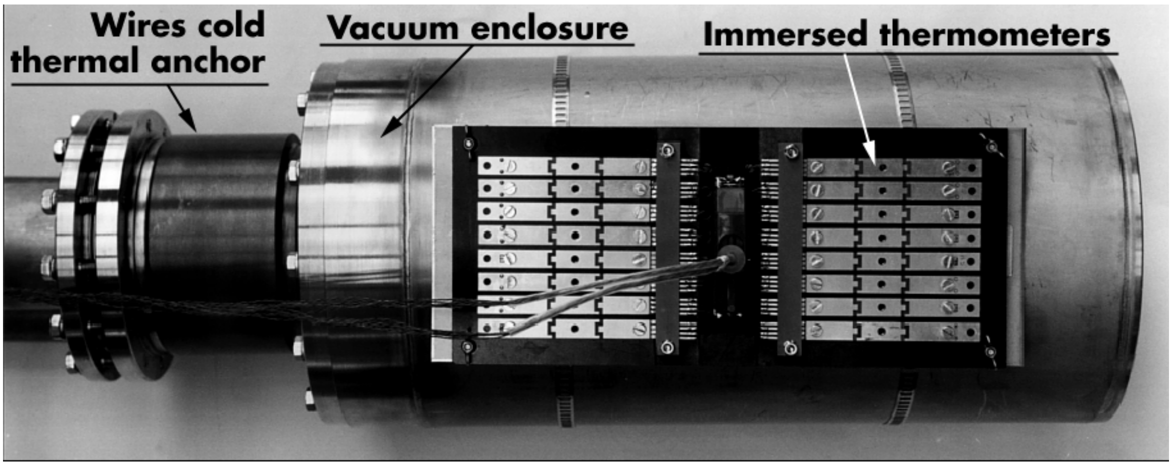
(a) at the low temperature end, a foil of Kapton® onto which all the wires are printed (319 copper strips) is used; this foil is pressed against the inner surface of a copper tube, heat is transferred to the cryogen through the tube wall,

(b) five disks fabricated by using printed circuit board technique are used for heating-up the wires when necessary ; these disks are also used for distributing the electrical wiring to the thermometers.

Outside the vacuum enclosure, 60 thermometers are furthermore installed in order to increase the calibration throughput ; these sensors are calibrated immersed in the surrounding liquid helium bath in the 1.6 to 4.2 K temperature range.



a)



b)

Figure 1. Insert (a) isothermal substrate with thermometers mounted and showing the wires heaters and (b) with vacuum enclosure and immersed thermometers.

Process

The flow scheme of the installation is shown in Figure 2. The insert holding the isothermal substrate is immersed in either liquid helium or nitrogen. For transferring liquid helium, the gas pressure of a 500 liter storage dewar is increased by using a control valve FCV1 that regulates the gaseous helium flow FT1 at the outlet of the calibration cryostat, the transfer is interrupted after reaching a pre-defined liquid helium level or if any critical measurement exceeds a safety threshold.

The substrate temperature is lowered by using gaseous helium as heat exchange gas, its pressure is regulated by a pressure control valve PCV2; this valve is a programmable micro-valve capable of adjusting the pressure between 10^{-5} and 100 mbar. After reaching a pre-defined temperature level, the feeding valve is closed, the vacuum is re-established (typically better than 5 10^{-5} mbar as measured by a room-temperature device - PIT3 in Figure 2) and the temperature of the substrate is stabilized (typically to within better than ± 1 mK) using an electrical heater.

The liquid helium bath temperature is varied using a butterfly valve PCV3; a simple PID control loop is not suitable for regulating the bath temperature because the optimum PID parameters depend strongly on the operating temperature.

After reaching the lowest calibration temperature, the system is warmed-up using various electrical heaters; during this procedure it is also possible to acquire calibration data.

Control and acquisition equipment

A Programmable Logic Controller (PLC) is used for managing all the safety routines, the closed-loop controls, the sequence of temperature plateaus and the synchronization of the acquisition equipment. The man-machine interface is provided by a Macintosh® computer running LabVIEW®. With a fully automated procedure a complete temperature cycle is estimated to have a duration of about one week.

The data acquisition equipment is of laboratory type; an IEEE-488 bus is used for communication between the instruments and the computer running LabVIEW®. The main components are a resistance bridge with dedicated scanner for measuring the working standards, a voltmeter, a programmable d.c. current-voltage source and a 400-channel scanner. For controlling the performance of the calibration equipment, various standard type resistors with an accuracy of about 5 ppm are used. At present the calibration data is stored in hard disk as flat files only and the post-processing of data is somewhat difficult because of the relatively large amounts of data to handle. This analysis should be easier once a data-base application is available for storing and retrieving this data.

EXPERIMENTAL RESULTS

For performing a calibration it is necessary to have at least one temperature reference which is used for comparison with the thermometers attached to the isothermal substrate. In our substrate we typically install between 3 to 5 working standards that are calibrated in a different apparatus [4]. The working standards are compared periodically with a set of four secondary standards that are traceable in the 1.5 K to 30 K range to standards maintained in a national metrological laboratory. The working standards are not traceable above 30 K but the measurements suggest that the quality of the temperature sensor used for calibration in this range is sufficient for our application (e.g. better that 0.25 % on the measured temperature). Figure 3 shows the temperature spread between 3 working standards during one temperature cycle covering 1.6 K to 300 K ; it can be seen that the maximum dispersion is below ± 2 mK. This demonstrates the good repeatability with the data obtained from our standard inter-comparison apparatus. The data presented assume that during a calibration scan there is no temperature drift of the substrate ; better accuracy should be obtained by measuring this drift. This also shows that, within the measurement errors, it is not possible to detect a temperature gradient along the substrate (the working standards are installed at opposite ends).
The repeatability of the calibration for the 60 sensors installed in the isothermal substrate is assessed by performing two temperature cycles between ambient and 1.6 K; thermometers

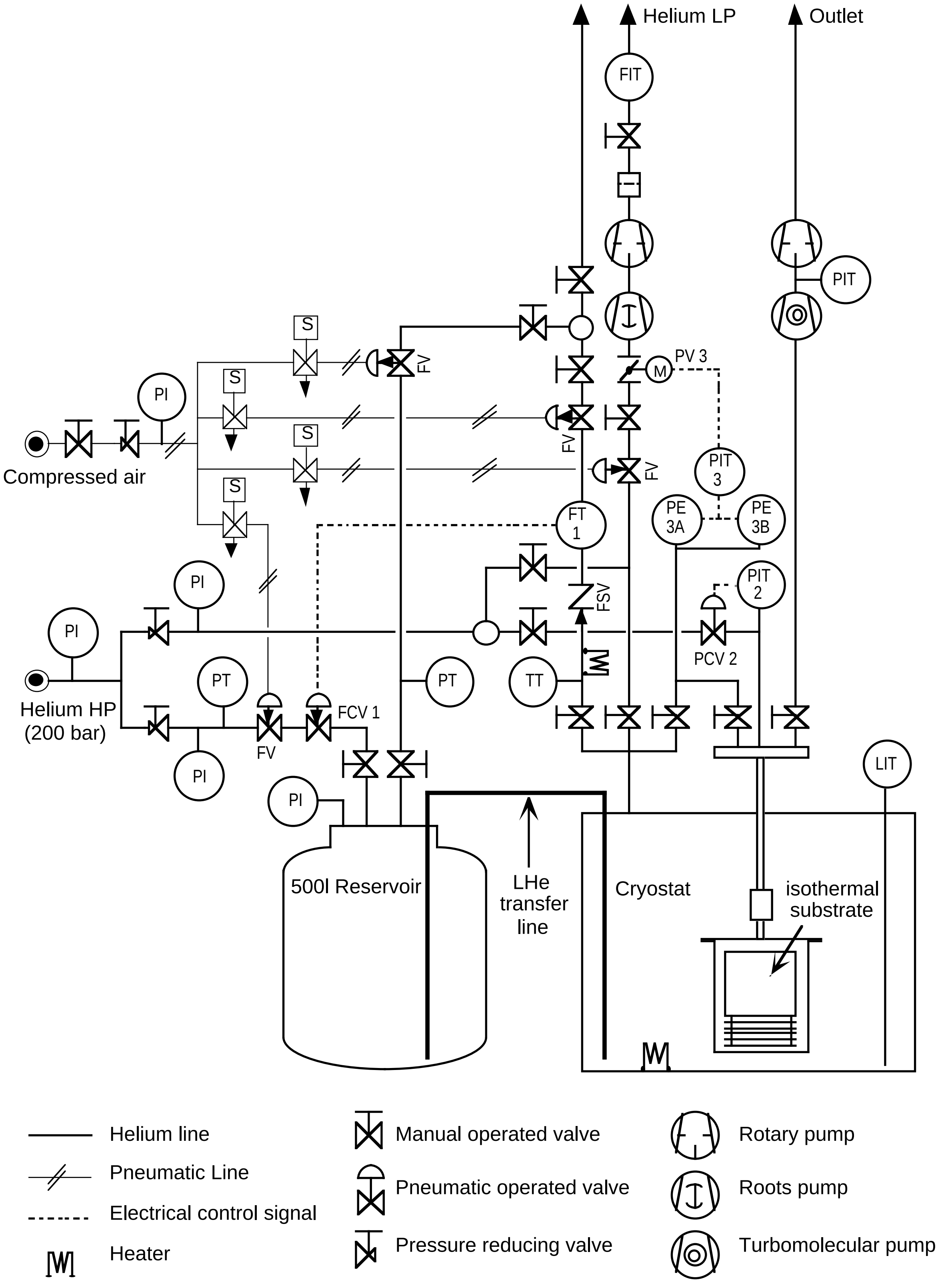


Figure 2. Flow scheme of the calibration facility. Letter code is C control, E element, F flow, I indicator, L level, M motor, P pressure, S solenoid, T transducer and V valve

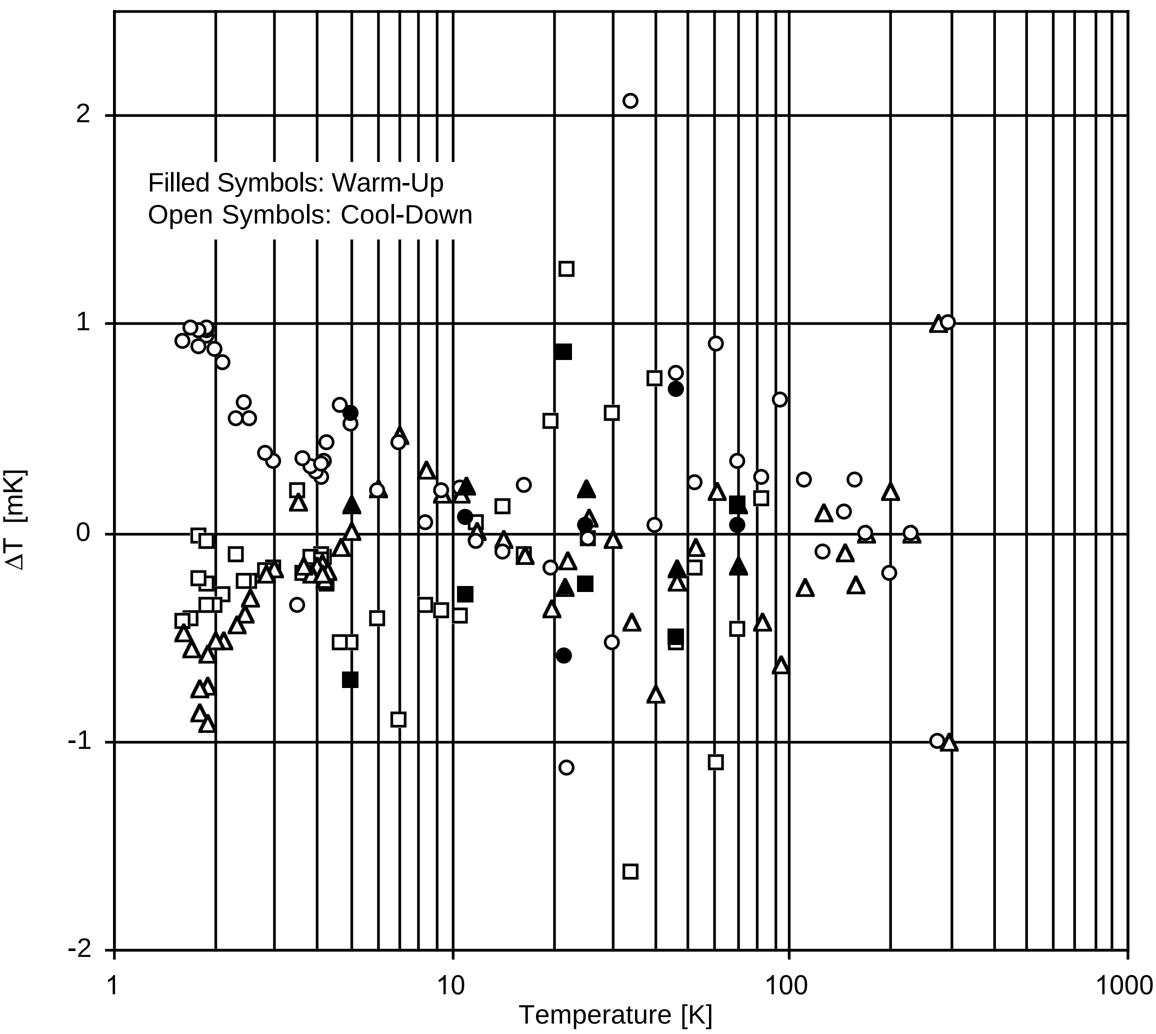


Figure 3. Temperature spread observed in the 1.6 to 300 K temperature range between three high quality RhFe temperature sensors used as working standards. One of the working standard (square symbols) is calibrated only below 90 K.

located on the lower (upper) sector of the cylindrical substrate are removed and installed in the upper (lower) sector before starting the second cycle. This measurement should reveal any temperature gradient or systematic error, within the stability over temperature cycles of the physical parameters determining the sensor characteristics. The temperature sensors examined during this test are: 58 CERNOX SD-1050, one Allen-Bradley type carbon sensor and one Russian TVO-type[5], all of them mounted in CERN's industrial thermometer support[3]. Figure 4 shows the reproducibility of the measurements ; it can be seen that above 150 K, there seems to exist a temperature gradient along the surface of the isothermal support ; this gradient is not observed with the working standards as shown in Figure 3. Below 100 K the repeatability of the measurements is better than ± 10 mK and Figure 4b suggest that it improves as the temperature is decreased. The spread in the repeatability at higher temperatures is probably the consequence of the type of sensors investigated: as the temperature is raised the variation of resistance with temperature decreases and a small variation on the sensor characteristics can account for a relatively large measurement error.

CONCLUSION

A calibration facility capable of calibrating a large number of thermometers has been described. The self-consistency between the set of working standards is similar to what is observed in a high-accuracy metrological apparatus, showing that the facility described in this paper has the potential of having an accuracy better than ± 2 mK in the 1.6 to 300 K temperature range.

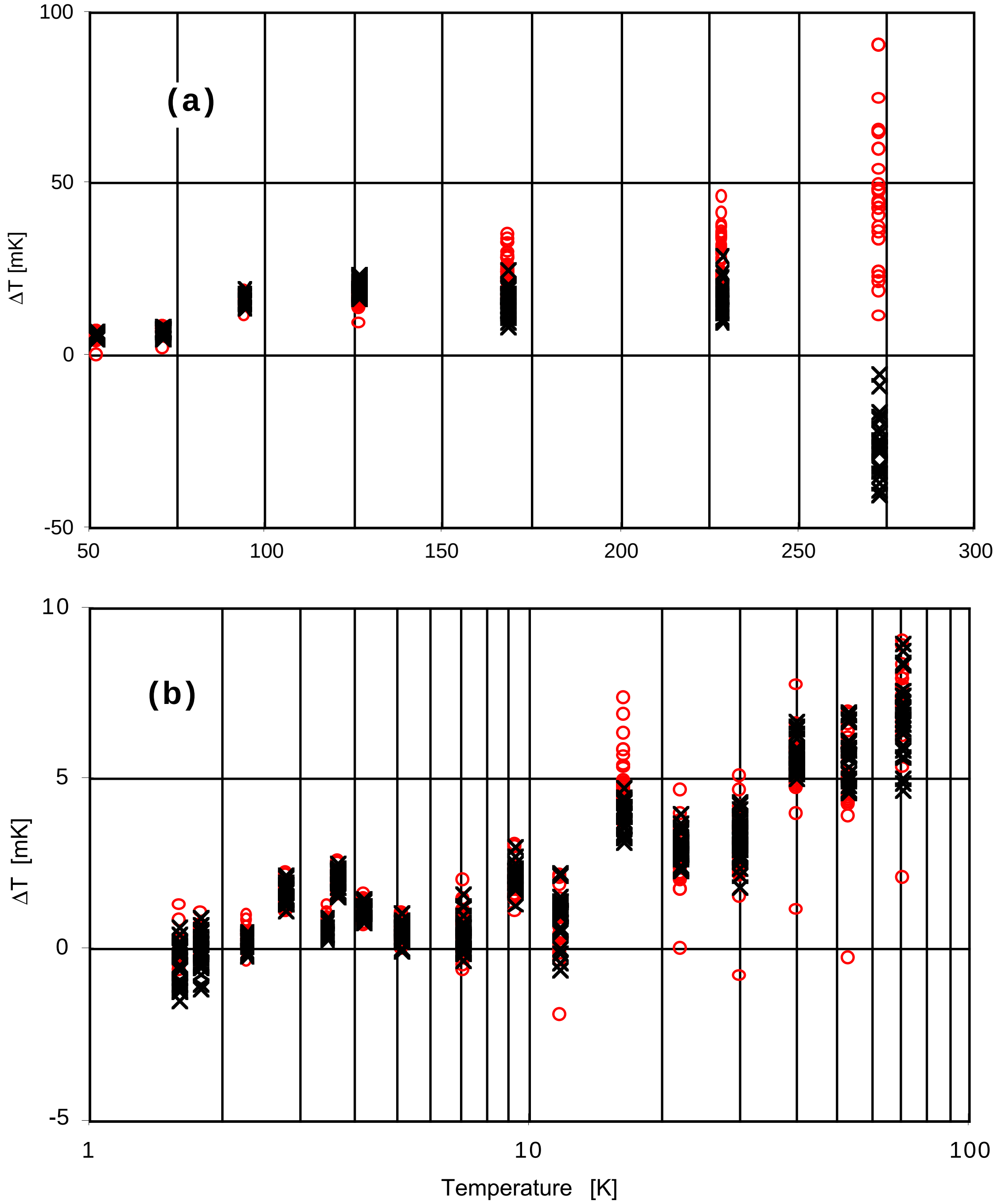


Figure 4. Reproducibility measured for 60 temperature sensors during two thermal cycles. "O" and "X' symbols correspond to sensors installed in the upper and lower sector respectively during the first temperature cycle. Their positions are inverted for the second cycle. (a) high temperature and (b) low temperature.

It is seen however that the industrial-type thermometers have a much worse repeatability, although it improves with decreasing temperature. The data also suggest that a temperature gradient exist along the substrate for temperatures above 150 K. The accuracy of the calibration facility presented in this paper can be further improved by performing a new series of tests to assess the origin of this gradient. Nevertheless the results demonstrate that the installation absolute accuracy is much better than 0.25 % of the measured temperature, which is the requirement dictated by the LHC cryogenic system.

In order to increase the overall throughput of this installation, an Oracle® database for managing the calibration data is being designed and new automatic routines should be implemented to be able to work without the assistance of an operator.

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REFERENCES

1. L. R. Evans, The Large Hadron Collider Project, in: “Proceedings of ICEC16-ICMC”, Kitakyushu - Japan (1996), p. 45
2. V. Benda et al., Conceptual design of the cryogenic system for the Large Hadron Collider (LHC), EPAC-96, (1996), P. 361
3. C. Balle and J. Casas, Industrial-type cryogenic thermometer with built-in heat interception, in: “Advances in Cryogenic Engineering”, Vol. 41B, Plenum, NY (1996), p. 1715
4. F. Pavese, V.M. Malyshev, P.P.M. Steur , D. Ferri and D. Giraudi, Routine calibration of cryogenic thermometers in the range 1.5-300K with an accuracy up to the milliKelvin level, and measurement of fixed points in sealed cells with a fully automated and self-contained modular apparatus, in: “Advances in Cryogenic Engineering”, Vol. 41B, Plenum, NY (1996), p. 1683
5. V.I. Datskov and J.G. Weisend II, Characteristics of Russian carbon resistance (TVO) cryogenic thermometers, Cryogenics, Vol 34 (1994), p. 425