Liquid helium level sensors on a PCB carrier with integrated temperature reading

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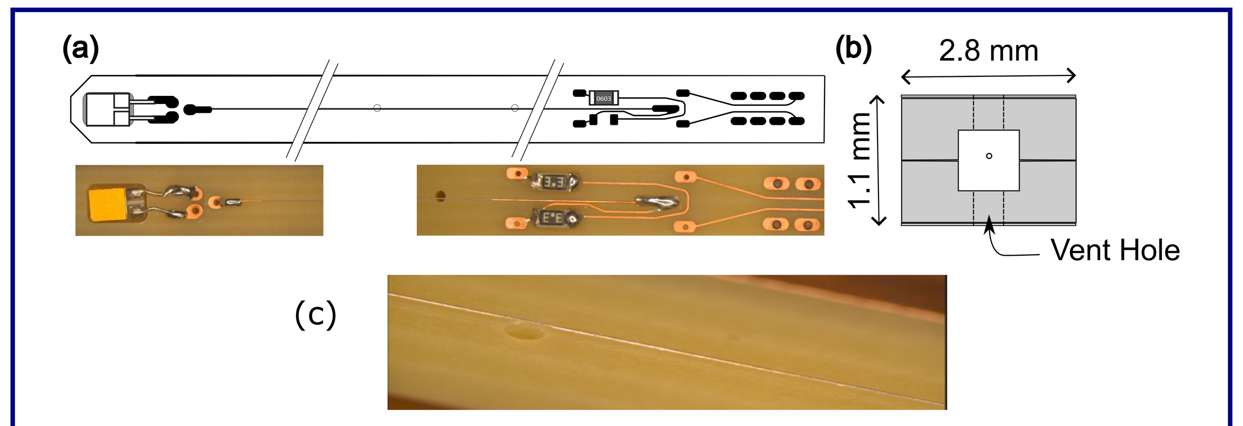
Abstract

A flexible liquid helium level gauge has been developed, it is based on a NbTi superconducting wire attached to a PCB (Prototype Circuit Board) carrier including two surface mounted heating resistors and a Cernox© temperature sensor at the bottom tip of the gauge. The superconducting wire selected is made of a single 0.049 mm NbTi filament with a copper cladding resulting in a wire overall diameter of 0.079 mm. The copper cladding is removed by using standard PCB manufacturing chemicals instead of nitric acid, that is extremely hazardous to handle.
The temperature sensor at the tip complements the measurement of absolute pressure of the saturated liquid helium bath (1.8 K cold box phase separator) and provides useful information to assess whether liquid helium is present.

Design and Manufacturing

The liquid helium level gauge uses a copper stabilized NbTi monofilament superconducting wire with an overall and filament diameters of respectively 0.079 mm and 0.049 mm. The level gauge is carried by a PCB, its minimal dimensions are dictated by the desiderata of integrating a cryogenic temperature sensor and be able to insert the probe through a capillary with an internal diameter of 4 mm:

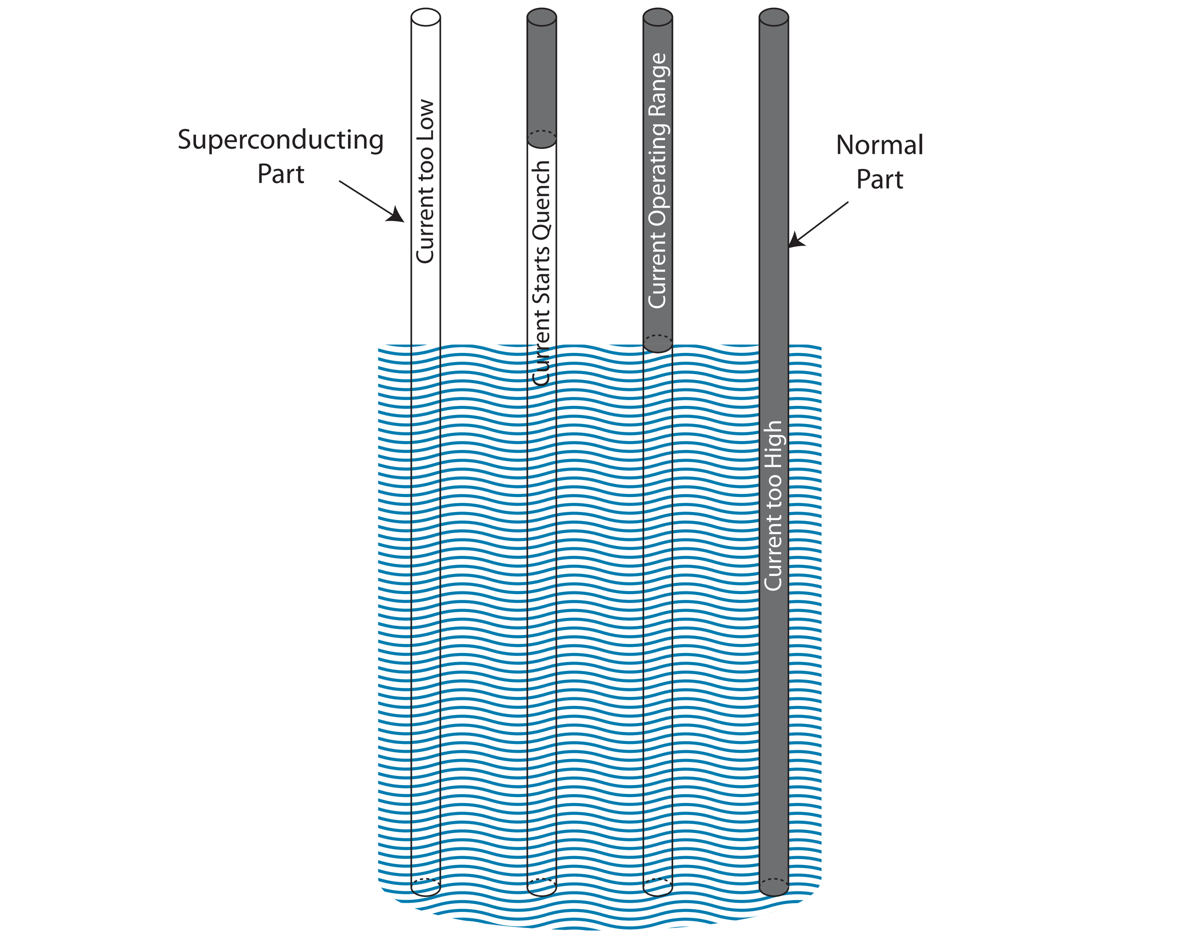


Liquid helium level gauge design: (a) top view without cover showing the temperature sensor, the ventilation orifices, the heating resistors and presence of copper cladding to solder on PCB pads. (b) cross section of 2.8 mm wide gauge. (c) presence of copper cladding due to non sufficient exposure to Ferric Perchloride (FeCl3)

A hot temperature spot is obtained by applying in series the excitation current through two SMD metal based resistors (size 1608 metric). The 3.3 ohm value of the resistors was selected in order to obtain a gas blanket when applying a current of about 75 mA; their separation with the wire is about 0.5 mm. The superconducting wire can be quenched even when fully immersed in both superfluid and normal liquid helium.
The differential thermal contraction from room temperature to 4.2 K for NbTi and PCB materials (assumed to behave as an epoxy resin) are respectively less than 0.3% and higher than 1% => NbTi wire without any slack.
The copper clad superconducting wire is surface soldered on the terminal pads, the cladding avoids the difficult task of obtaining a reliable electrical connection between a bare NbTi wire and the PCB copper pad.
The next step is passing the PCB panel though an etchant conveyor using Ferric Perchloride ($FeCl_3$), this step requires protecting the copper tracks and pads as well as both ends of the superconducting wire. Once the copper cladding is etched, the superconducting wire resistance is measured; its value is dominated by the wire length where only the NbTi filament is present.

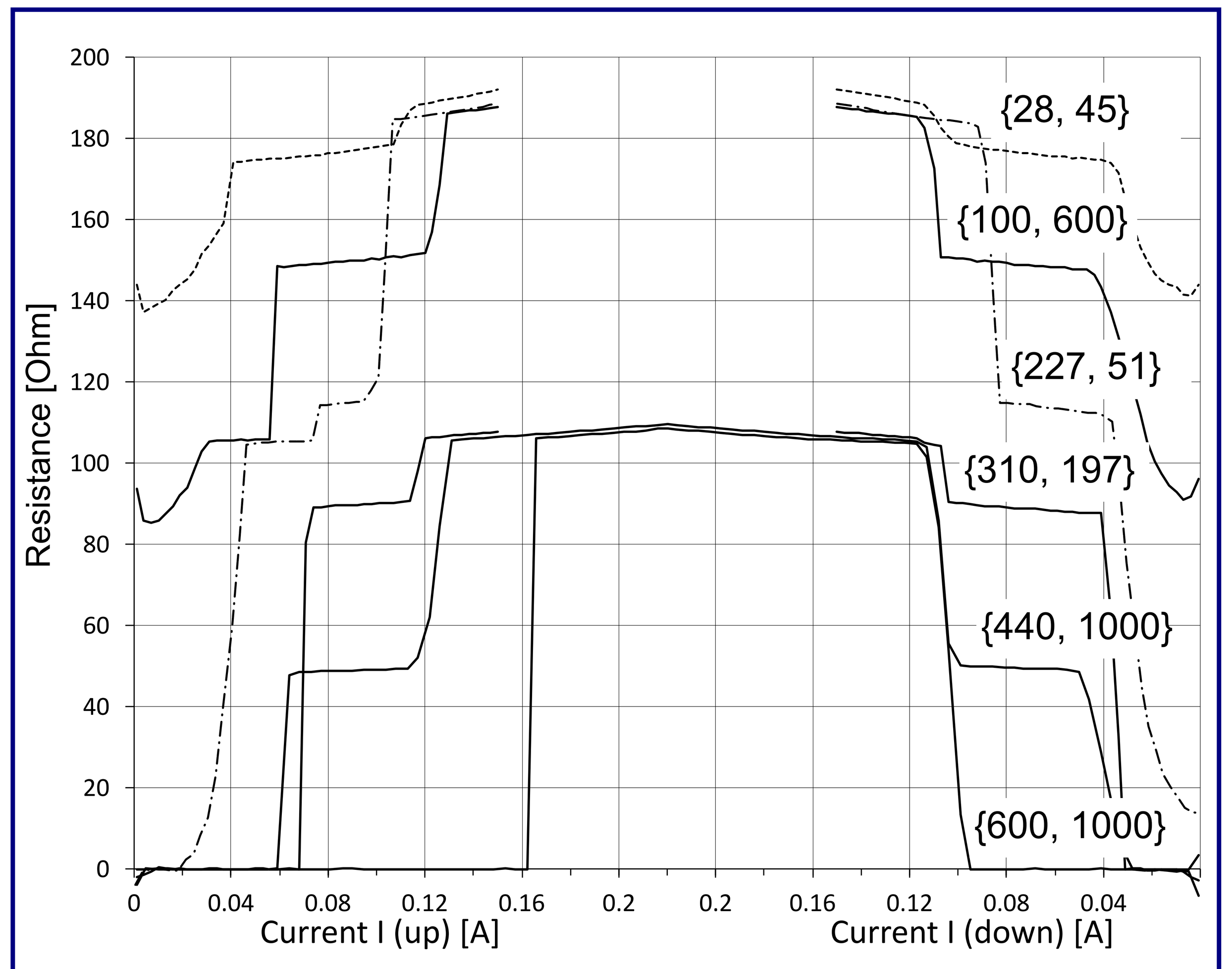
Characterization

The position of the normal-superconducting interface along a vertical superconducting wire depends on its current, assuming that a spot heater destroys locally the superconducting state.



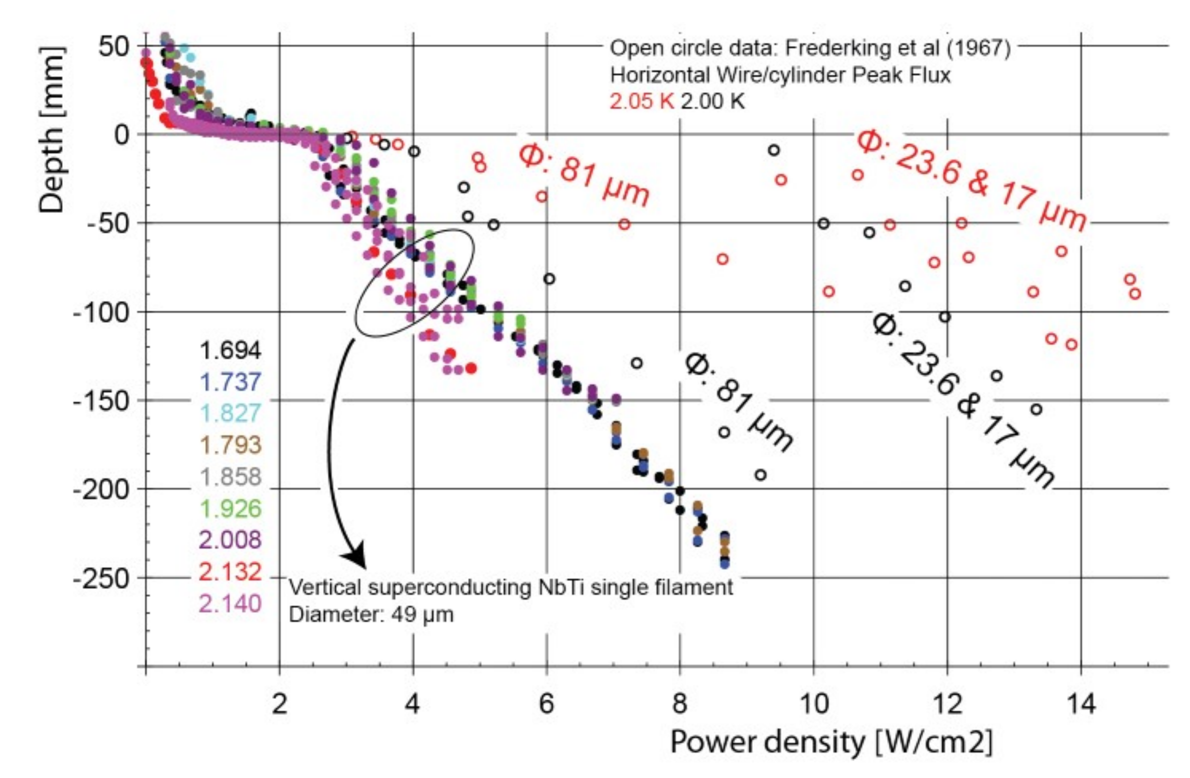
Superconducting level gauge: operational principle

A relatively slow current sweep is applied, and the equivalent wire resistance is calculated. The resistance versus current characteristics permit to set the level gauge operational conditions. The superfluid <-> normal LHe phase transition is critical because the "measurement" plateau is at its narrowest width while descending the sweep current.
The sweep current permits to select optimum currents for operation in either continous or pulsed mode:
BOOST: to destroy the superconducting state
MEASURE: to stabilize the normal-SC interface
IDLE: to reduce heat in-leak into the LHe bath



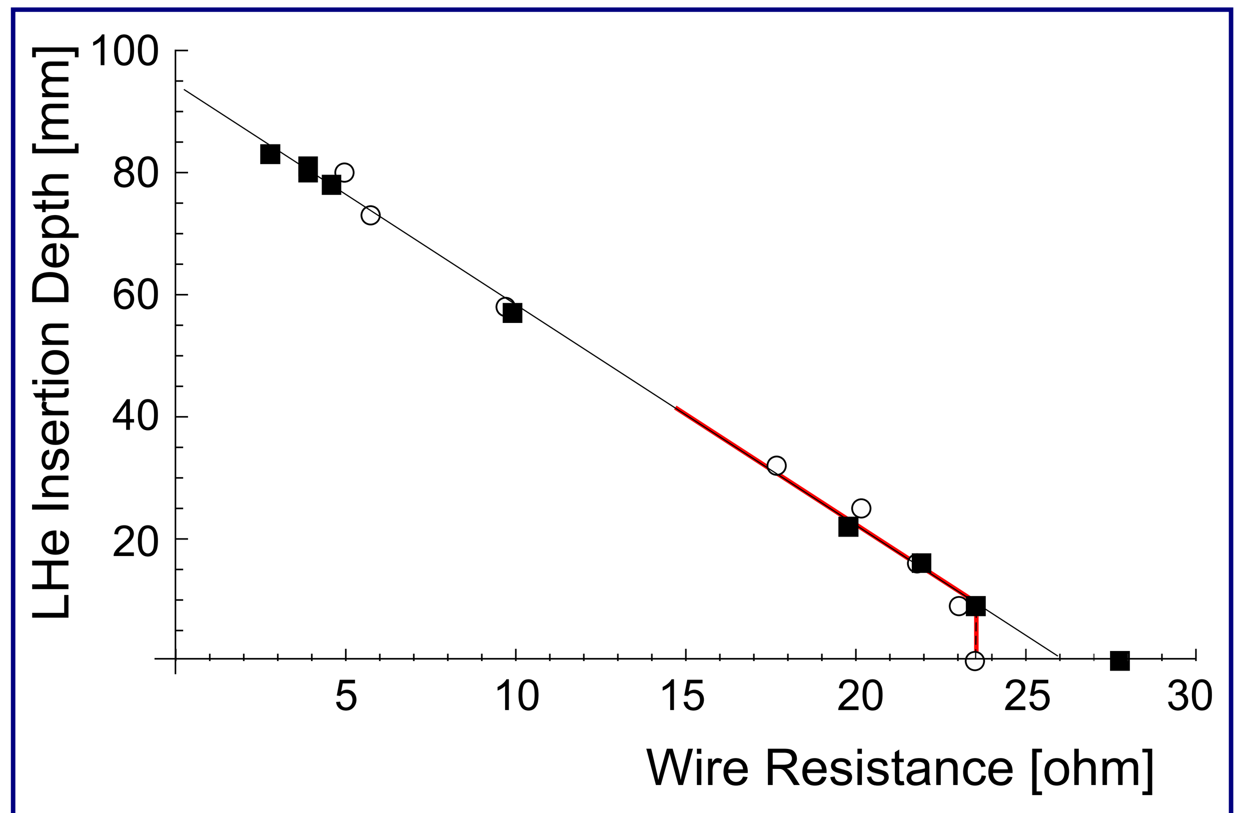
Experimental data for a level gauge with 600 mm active measurement length. Slow current sweep at various {liquid level insertion depth [mm], saturation pressure [mbar]}

When applying a slow increasing current sweep it is possible to deduce the peak flux to obtain a gaseous blanket aroung the superconducting filament. The measurement can be compared with literature data for superfluid helium (the peak flux depends on the depth):



Dependence on the immersion depth of the peak flux in superfluid liquid helium

Presence of copper cladding significantly increases the thermal exchange stopping the propagation of the normal zone above the liquid-gas interface



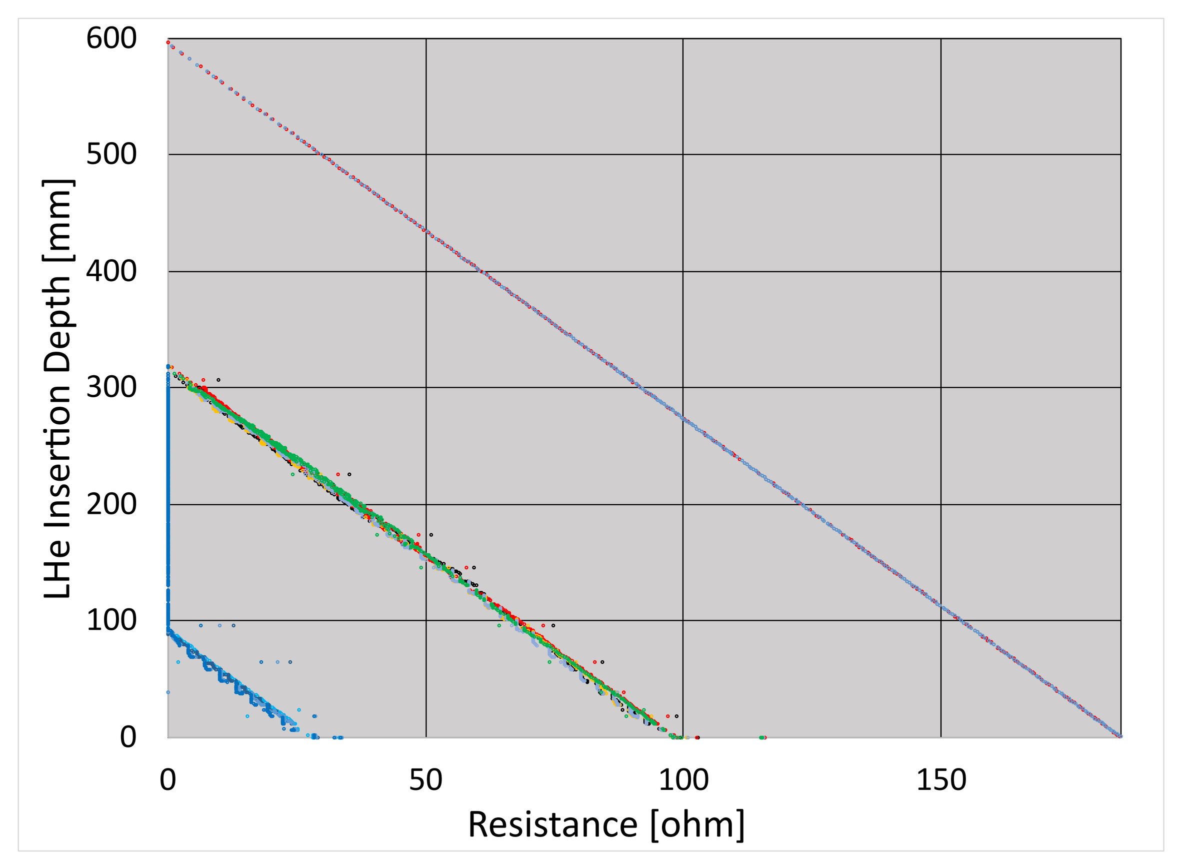
Resistance versus liquid helium immersion depth for two probes with an active length of 93 mm. One of the probes (Circle marker) exhibited traces of copper cladding at the bottom end, resulting in an active length reduced by about 10 mm

CONCLUSION

This paper presents the manufacturing of LHe level gauges based in NbTi wires, active lengths up to 600 mm have been manufactured although the feasibility of longer gauges up to 4000 mm will be investigated. The manufacturing process avoids the use if nitric acid that is much more hazardous in comparison with feric perchloride.
The temperature sensor at the end of the tip complements the process variables being measured as it can assess whether liquid helium is effectively present and provide an indirect measurement of the liquid helium bath saturation pressure.

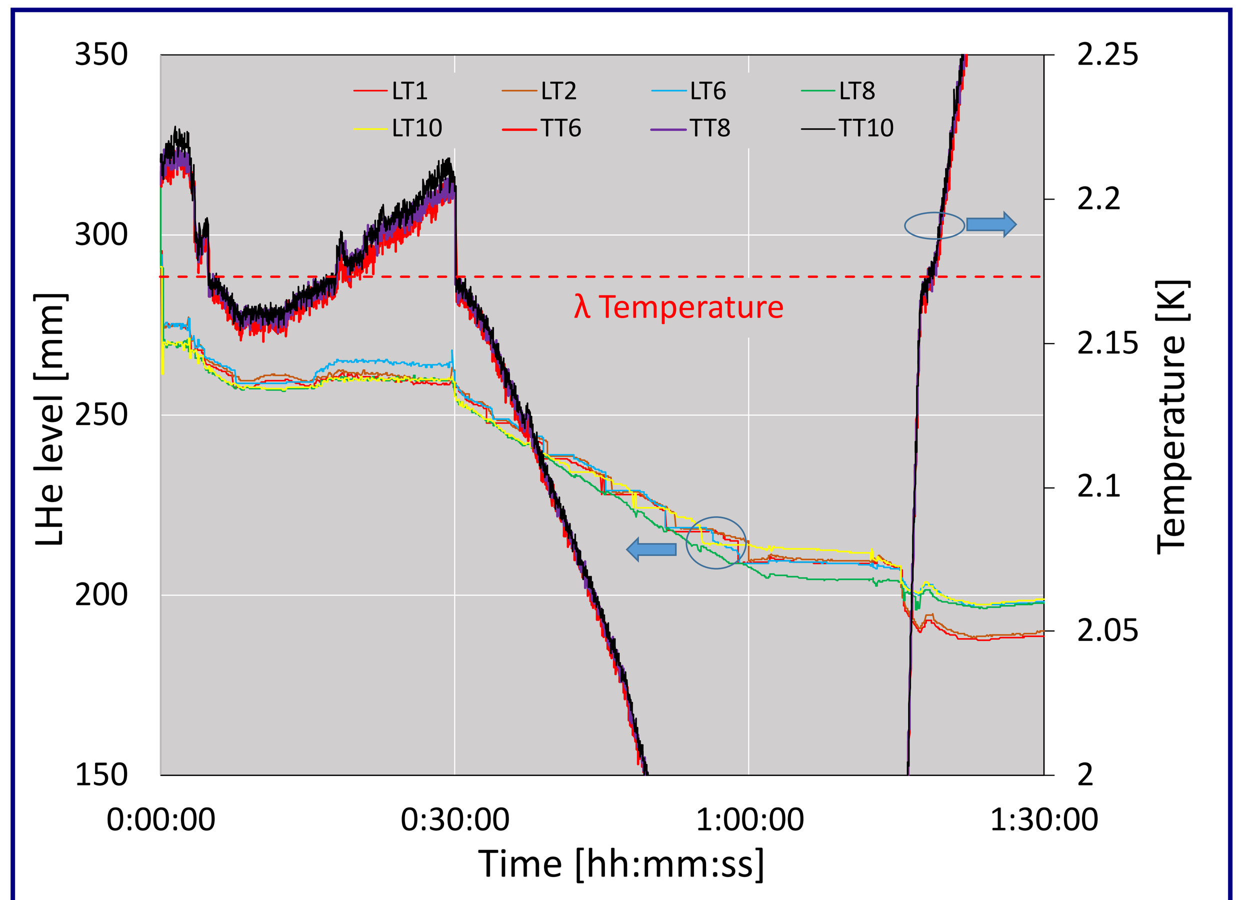
Nominal Operation

The level gauges were tested while filling and empting a LHe cryostat. The conditioning electronics is the CERN WFIP radiation tolerant electronics with a 100 mA boost and 60 mA measurement currents followed by a zero current standby period.
The data exhibit constant level plateau that fit the location of the venting orifices; the next iteration will reduce the hydraulic impedance to evacuate the evaporated gas by increasing the venting hole quantity and empty PCB cross-section.



Experimental data for 12 level gauges measured using CERN radtol electronics. Data is shown for 3 x 100 mm, 6 x 320 mm and 2 x 600 mm active length LHe gauges.

The level gauges are validated for measuring the LHe level when switching from the superfluid to normal state (or viceversa). The dynamic trend data show a rapid variation across the transition but it is within typical error obtained for level gauges based in superconducting filaments.



LHe level measurement during the transition between liquid helium superfluid <=> normal phases.

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