The Background and the Need for millidegree thermal control

The South Dakota Underground Laboratory, purpose-built for sensitive Torsion Balance Experiments, already has high thermal stability — the passive shielding gained by going underground, suppresses diurnal (24-hr) and semi-diurnal (12-hr) temperature waves to amplitudes well below 50 mK.

However, variations of the temperature not only couple directly to the motion of the torsion balance but also affect nearly every part of a system (the optics, the electronic, mechanical, software, gain, noise, or wave, systemic errors that seem to affect the signal). That is why the sensitive Active Optical Layout with an angular resolution of 3 x 10^{-5} rad is affected by these systemic temperature variations. The target Equivalence Principle Test to a sensitivity of 1 part in 30, so we therefore need to suppress the residual temperature wave to amplitudes below 1 mK.

We describe key aspects of a complete Active Thermal Control System that surrounds the underground, suppresses diurnal (24 hr) temperature waves to amplitudes below 1 mK.

Finally, OUR RESULTS (actual performance of the full system).

Reliable Temperature Measurement

Thermistors (YSI # 46016 B) are our preferred choice of temperature sensor, since their "signal" is easily read in "cold" conditions. Much effort went into establishing their stability and interchangeability, key factors in the reliable functioning of a large, distributed control system.

Thermistors have a highly non-linear relationship. The best empirical description of the Netpoint N 1144K Thermistor is:

\[
1 = e^{2.645} \ln (R_n) - e^{0.011} \ln (R_n)
\]

Each thermistor has slightly different characteristics; for each of the control unit (not shown in the block diagram), we measured the ratio (for every thermistor) and used the empirical equation to calculate the thermistor resistance.

We CROSS-CALIBRATED our thermistors inside which we call a "Multi-Layer Thermal Enclosure", engineered to reduce thermal gradients between individual thermistors in the ensemble of thermistors being calibrated. The assembly of thermistors include a designed "Master Thermistor" that is used to follow the manufacturer's standard 4-pin curve.

Individual thermistors are replacement to the Master Thermistor's temperature for far better than 1 mK. Calibration studies on the same set of thermistors performed nearly every 12 months but over 4 years show that different thermistors age or drift slightly differently. However, over 1 year period they can be used interchangeably within a precision of about 0.1 mK.

The Thermal-Mechanical Enclosure

Active Stabilization of Temperature has to be delivered over a region about 2.6 m in diameter x 8 m in height. Central to our system an in-house, modular scaffolding structure. The scaffold is fitted 24 identical thermal panels (see each on the sides of the octagon, and distributed in three layers).

As installed in the Underground Laboratory.

A modulated card, with 8 such Power Amplifier modules.

At right, a module card that has this BGA chip mounted at centre, and multiple ports for data and control.

A Report on the RESULTS – 1

Some representative Temperature Logs BEFORE The Thermal Control System was switched on:

A Report on the RESULTS – 2

Some representative Temperature Logs AFTER The Thermal Control System was switched on:

In Summary

The development of the thermal control system has involved a number of different steps. Just a few of these are:

- growing the system (i.e. Thermistor) sensitivity, interchangeability and long-term stability;
- developing stable "sensor heads" that correspond accurately;
- developing the ISHA Board around the AD5533, associated electronics, Power Amplifier modules;
- development of software to control the entire system;
- and the Earth –

We have subsequently made small but steady improvements on the system, such as the "shifting" of the air inside the thermal enclosure to reduce vertical temperature gradients. More recently the system has been put to the LabVIEW platform, and uses NI hardware to replace the ISHA board.

Acknowledgements

Dr. T. M. Prasad contributed during early phases of the development of the system, especially with a survey of ISS for STH. R.K. Banerji very kindly provided much help in the early stages. The greater contributors are of course from our colleagues in the Experimental Laboratory, both in Mumbai and Bangalore, especially D.B. More, C. Rajagopal, J.C. Hallang, R. Raman, and F.S. Murray.

Sony Wagner participated in early attempts at characterizing the system.


Abstract: We describe features of an Active Thermal Control System that suppresses long-period (diurnal and semi-diurnal) temperature variations in a volume of 30 m^3 to amplitudes below a millidegree Centigrade. The system possesses attributes of modularity that allow it to be scaled to arbitrary size. It is therefore likely to be of interest to the larger community engaged in Precision Experiments.