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NATURAL ENVIRONMENT RESEARCH COUNCIL

Experiences in Designing a Low-cost Temperature Controlled Variometer Enclosure

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ON GEOMAGNETIC OBSERVATORY INSTRUMENTS,
DATA ACQUISITION AND PROCESSING
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Abstract

Magnetic observatories have traditionally used small buildings or huts to provide a stable, protected and temperature controlled environment to accommodate the sensitive magnetic instruments. As instruments have evolved they have reduced in size and become less reliant on absolute mechanical stability but still require good temperature stability. Maintaining a stable temperature in large older buildings can be difficult and expensive due to their volume, the substantial thermal losses and undefined thermal properties of the construction materials.

This report describes a modern instrument housing comprising a small-scale enclosure and low-power, non-magnetic heating elements controlled by a proportional–integral–derivative (PID) temperature controller. Operating magnetometers in a compact environment with other equipment requires careful selection of heating elements and minimising any sources of local interference. The specifications and calculations for the enclosure design, materials and temperature control system are presented with results of long term temperature stability performance in comparison with traditional observatory housings. The disadvantages and benefits of operating instruments in small enclosures are also discussed.

Introduction

The British Geological Survey (BGS) operates three UK magnetic observatories and five overseas. The UK observatory buildings were originally designed to accommodate larger instruments and as a result have become an inefficient use of space and heat for housing modern instruments; Eskdalemuir observatory requires over 4 kW of heating to maintain the temperature in the building that houses the primary instrument. The BGS operates Danish Meteorological Institute (DMI) FGE fluxgate magnetometers for all of its variometers.

BGS has developed a new low-cost enclosure which is currently used to operate backup variometer systems at Lerwick, Hartland and Eskdalemuir. This type of enclosure is also used to house the variometer at the re-established observatory in South Georgia. To quantify performance of the new enclosure, a comparison was carried out between the primary (GDAS1) variometer at Lerwick (which continues to use the older style of building) and the new enclosure that houses a backup variometer (GDAS2), for 2011 data. Design of the new enclosure focussed on minimising the volume and heating requirements whilst still ensuring a stable & magnetically clean operating environment for long-term magnetic recordings.

Enclosure Construction

Foundations

The foundations for the enclosure are formed from a shallow raft (0.2 m) of non-magnetic cement. This construction provides adequate stability providing the fluxgate sensor has tilt-compensation.

Enclosure Materials

The enclosure is fabricated from a two layer fibre-glass wall with a 15 mm polystyrene core for insulation. This combination gives the structure strength and durability whilst still remaining light enough to transport by hand.

Insulation

The inside walls and floor of the enclosure are clad with 75 mm, foil-backed polyurethane insulation panels to further reduce heat loss and all seams are sealed with silicone rubber to minimise heat loss through air exchange.

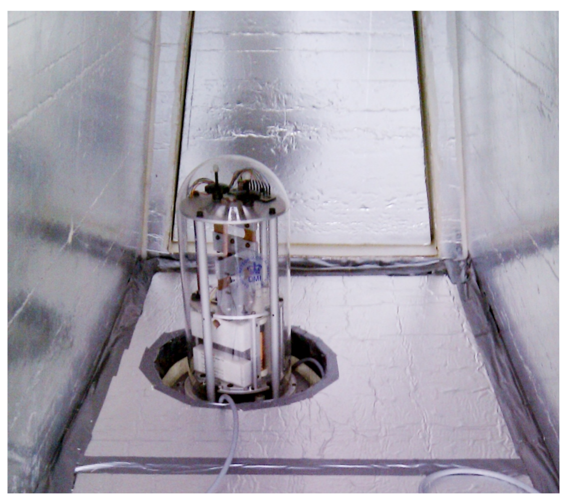
Layout

The fluxgate electronics and heater are located at the opposite end of the enclosure from the sensor to provide maximum separation and promote a more stable temperature gradient across the sensor. The sensor is mounted directly on the concrete raft through a gap in the insulation to provide better stability from wind vibration on the main structure.

External Dimensions

Height: 1.5 m, Width: 1.0 m, Length: 2.0 m (tapered sides to reduce wind vibration).

Thermal Loss Calculations



Given the simple construction and materials of the enclosure, it is possible to estimate the thermal loss characteristics of the system. Here heat loss is dominated by a combination of conduction and natural ventilation (air change). Radiation losses are negligible due to the low emissivity foil on all inside surfaces.

Conductive Losses

The rate of heat lost due to conduction (dQc/dt) is related to the material thermal conductivity (k), surface area (A), temperature gradient (ΔT) & material thickness (x) by equation 1. For a wall construction using a combination of different materials and thicknesses, a total thermal resistance (R-value) can be determined by combining the individual thermal resistance values for each layer of material (equation 2 & 3). The total thermal resistance of the enclosure walls and floor is summarised in Table 1.

$$\frac{dQ_c}{dt} = \frac{k_m A \Delta T}{x} \qquad (1)$$

$$R_v = \frac{x}{k_m} \qquad (2)$$

$$R_v = R_{v1} + \cdots + R_{vn} \qquad (3)$$

$$\frac{dQ_c}{dt} = U_t A \Delta T \qquad (4)$$

$$\frac{dQ_v}{dt} = N V C_v \Delta T \qquad (5)$$

Material	x (mm)	k_m (W/mK)	R_v (m^2K/W)
Fibre-glass	03 mm	0.04	0.075
Polystyrene	15 mm	0.03	0.500
Fibre-glass	03 mm	0.04	0.075
Insulation board	75 mm	n/a	3.450
Total walls:	**96 mm**	**n/a**	**4.100**
Total floor:	**75 mm**	**n/a**	**3.450**

Table 1 Thermal Resistance of Enclosure Materials

The total thermal transmittance (U_t) for the enclosure construction is the reciprocal of the total thermal resistance (0.243 W/m^2K and 0.290 W/m^2K for the walls and floor respectively). The thermal transmittance values allow calculation of the combined conductive losses using equation 4.

Air Exchange

The heat lost via natural ventilation (dQv/dt) is calculated (equation 5) as the rate of thermal energy lost due to air exchanges (N), for the volume of space being heated (V), volumetric heat capacity of air at 20 °C (C_v) and the temperature gradient (ΔT).

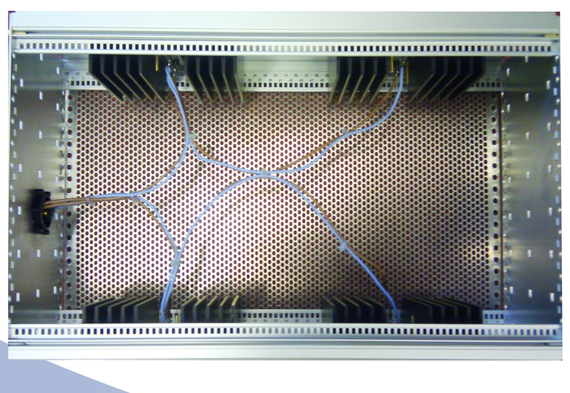
Assuming a set-point temperature of 20 °C, winter external temperature of -10 °C, enclosure volume of approximately 3 m^3, wall area of 11 m^2, floor area of 2 m^2, C_v = 1.297 kJ/m^3/K and a conservative 1 air exchange per hour, the total predicted thermal losses can be summarised in Table 2.

Due to the low thermal losses, a low-power heating system can be designed to run from lower voltages, simplifying many aspects of the enclosure design.

Type	Rate of Thermal Loss
Conductive (walls)	80.5 W
Conductive (floor)	17.4 W
Ventilation	32.4 W
Total:	**130.3 W**

Table 2 Thermal Losses Summary

Non-magnetic Heater



Requirements

A non-magnetic and non-inductive heater is essential when the magnetometer and heater are in such close proximity. Sourcing commercial non-magnetic, low-voltage, heaters is a common problem so BGS chose to construct bespoke heater elements specifically for this application.

Construction

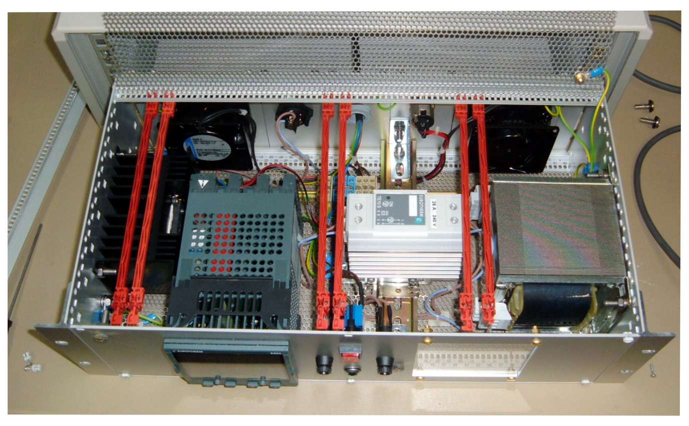
The heating element comprises four Vishay 50 W (56 Ohm) thick-film power resistors mounted on 1.3 °C/W anodised aluminium heat sinks. The heat sinks are then mounted in a standard 19" aluminium rack vented rack enclosure with all magnetic parts removed. The use of standard parts simplified fabrication and future proofs availability of components whilst keeping the cost of the system low.

Driving the heating element at 48 VAC and with small line losses produces a maximum power output of approximately 160 Watts. The magnetic 'signature' of the heater is undetectable at distances > 0.5 m from the variometer sensor. This type of heater has proved to be very reliable over the long-term, having been operated at several of the BGS observatories for a number of years without failure.

Acknowledgments

Ralph Plastics Fabrication Services - Construction of the fibre-glass Enclosure

PID Temperature Controller



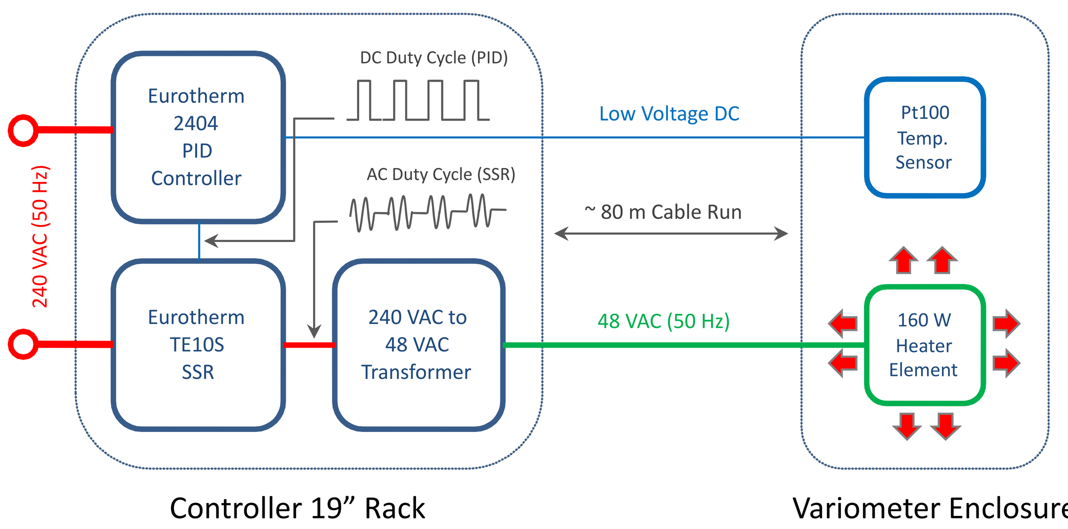


Figure 1 Enclosure Temperature Control System Schematic

Control System

The enclosure temperature is regulated using a Eurotherm 2404 PID process controller. The controller proportions power to a non-magnetic heating element in the enclosure via a TE10S solid state relay and 220 VAC to 48 VAC step down transformer (Figure 1).

Switching Relay

The TE10S relay employs zero-volt switching to ensure that the AC supply is only triggered on and off at zero points in the sine-wave cycle. This prevents harmonics of the supply frequency being generated (a possible source of noise in the variometer) and also extends the operating life of the heater element by reducing high-frequency currents. For optimal performance, the three PID control parameters need to be tuned to the operating environment and the response time of the system. The Eurotherm 2404 does this by initiating (on set-up) a tuning cycle that forces the temperature in the enclosure to oscillate, allowing it to determine the ideal PID settings [2].

Low-voltage Supply

The 48V AC supply is used to implement Separated Extra Low Voltage (SELV) protection from electric shock [1]. SELV permits un-armored power cables, due to the lower voltage and electrical isolation offered by the transformer. This relaxes the power cable specifications and prevents introducing magnetic contamination due to steel armouring. Due to the lower voltage, low resistance cables have to be used (minimum of 2.5 mm^2) to reduce line losses.

Performance

Temperature Stability

To assess the performance of the enclosure, both the short-term and long-term temperature stability of the system has to be considered. Figure 2 shows the 2011 variation in the enclosure measured at the sensor head (green trace). The lower traces show the external temperature extremes for each day (annual range of 21.1 °C). This long-term plot shows the PID controller is maintaining the temperature over the year to within about 2 °C of the set-point and that this variation is manifest as a long-period deviation.

Figure 3 is a statistical view of the daily (or short-term) temperature stability of the system. The histogram indicates that for 358 days of the year (98%) the temperature in the enclosure (1-minute samples) did not deviate by more than 1 °C from the set-point. This was during a period where, the average daily external variation was 4.2 °C and the maximum daily variation was 11.0 °C.

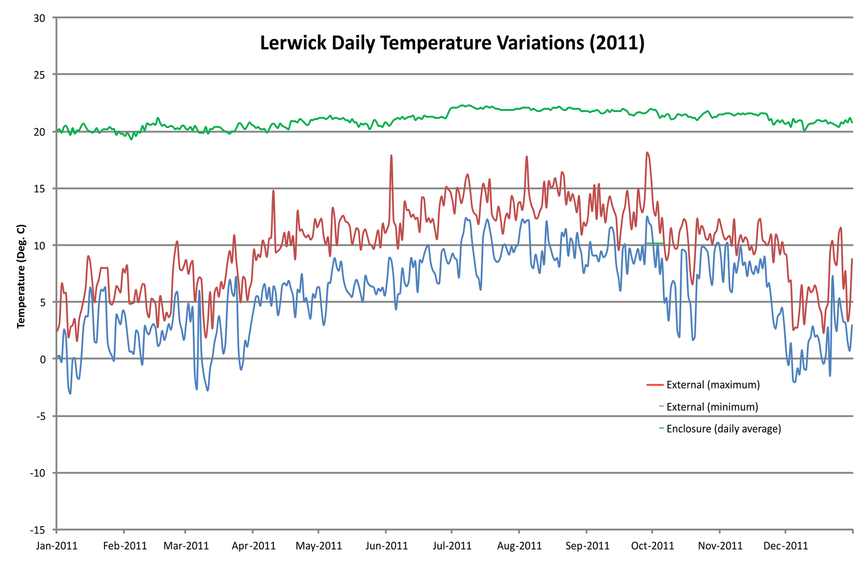


Figure 2 Long-term Temperature Stability

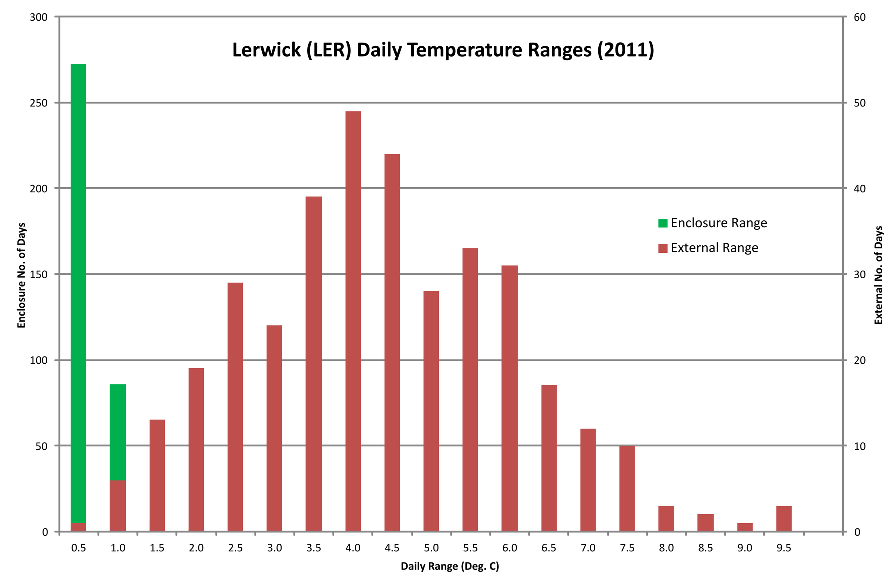


Figure 3 Daily Temperature Stability

Data Quality Comparison

To quantify the quality of the new enclosure (GDAS2), a comparison of the final data was carried out using the primary recording system at Lerwick observatory (GDAS1). Comparing the variometers in this way gives a measure of the total system performance taking into account any possible sources of contamination, noise or instability at the new enclosure.

Figures 4, 5 & 6 show the final data quality of this system compares well to the primary system. Over 95% of minute samples from 2011 differ by less than +/- 0.5 nT in the Horizontal (H) and Vertical (V) magnetic components.

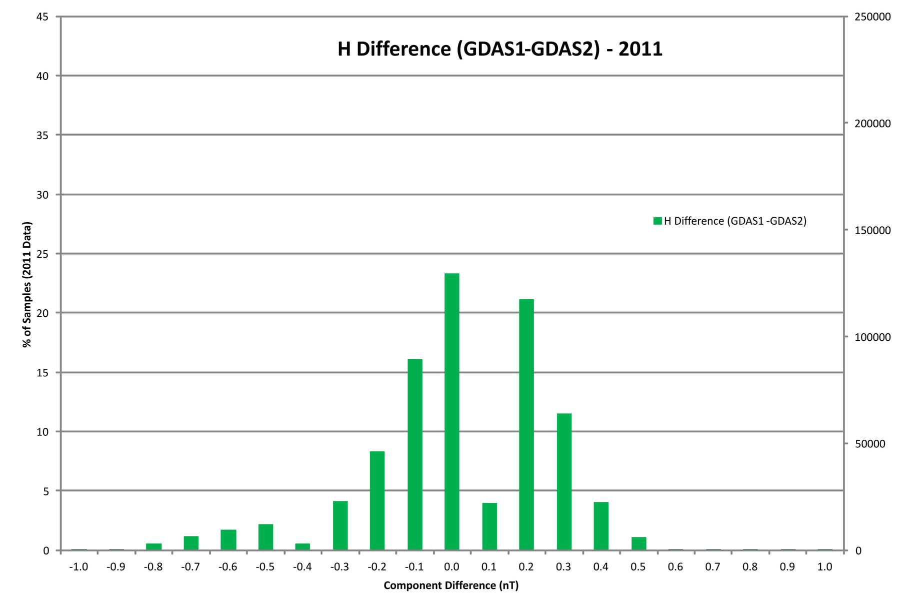


Figure 4 Horizontal Comparison Histogram for 2011

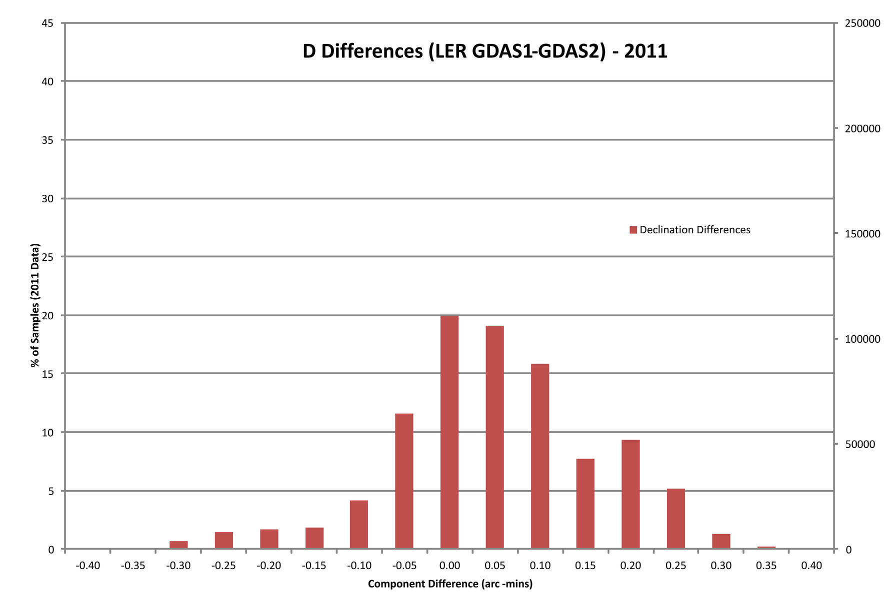


Figure 5 Declination Comparison Histogram for 2011

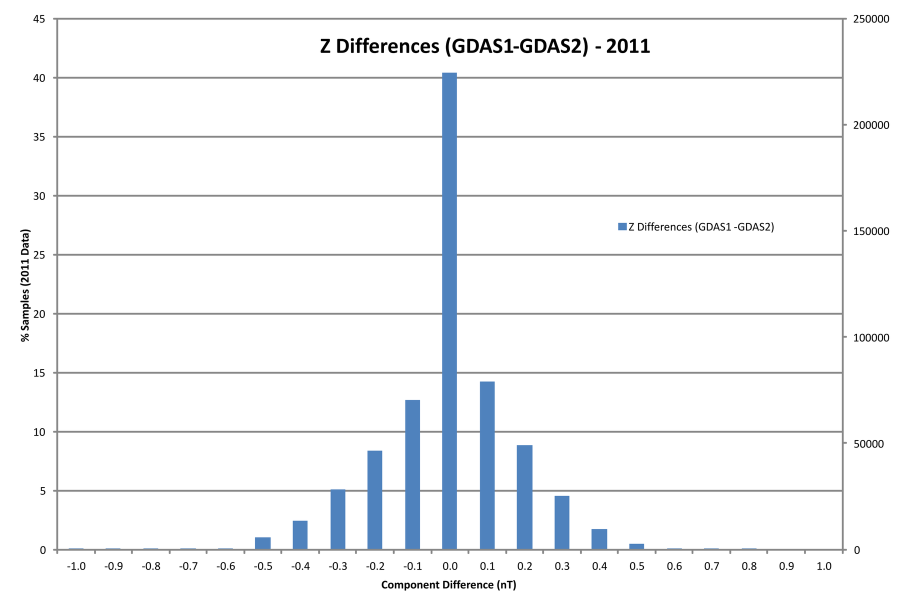


Figure 6 Vertical Comparison Histogram for 2011

Conclusions

Quality

Experience from operating the temperature control system shows the PID controller typically drives the heater load with a duty cycle of between 30-60 % over most of the year. This equates to roughly 50-100 Watts nominal power consumption which roughly agrees with the predicted thermodynamic performance of the system and the observed external temperature gradients for 2011 at Lerwick. The data quality analysis establishes that the new enclosure successfully provides a low noise environment for making high quality magnetic recordings and that any long-term temperature variations are being adequately modelled by the baselines used to produce final data.

Observations

In general, suspended magnetometer sensors don't require pillars mounted on bedrock and a shallow raft of concrete provides sufficient stability, reducing the cost and installation time. However, the concrete raft can be susceptible to tilt in locations where the soil is particularly soft and this was seen at Lerwick when a fault developed with the fluxgate sensor tilt-compensator. Daily drift was seen primarily in the H and D components until the sensor suspension system was repaired.

Due to the low thermal mass of the enclosure, temperature over-ranging can occur in the summer months; a solution to this would be to bank earth around the sides of the enclosure which would also allow a lower set-point to be used.

References

[1] *Requirements for Electrical Installations,* Wiring Regulations 16th Edition (BS7671:2001), The Institution of Electrical Engineers and British Standards Institute, The IEE, London, 2004.

[2] *Eurotherm 2404 Installation & Operation Handbook,* Issue 10.0, Eurotherm, 2004.