# *EXPERIENCES IN DESIGNING A LOW-COST TEMPERATURE CONTROLLED VARIOMETER ENCLOSURE*

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### *SUMMARY*

*Magnetic observatories have traditionally used small buildings or huts to provide stable and temperature controlled environments for housing sensitive magnetometer instruments. As magnetometer technology has developed, instruments have reduced in size and become less reliant on mechanical pier stability, whilst still relying on adequate temperature control. Temperature control in large, older, buildings can be challenging and expensive due to their volume, thermal losses and undefined thermal properties of construction materials. This report describes a modern instrument housing comprising a small-scale enclosure and low-power, non-magnetic heating element controlled by a proportional–integral–derivative (PID) temperature controller. Operating magnetometers in a compact environment requires careful selection of heating elements and minimising any sources of local interference. The specifications, thermal calculations, materials and temperature control system for the enclosure are presented with results of long term temperature stability and overall performance in comparison with traditional observatory housings. The disadvantages and benefits of operating instruments in small enclosures are also discussed.*

## 1. INTRODUCTION

The British Geological Survey (BGS) operates three magnetic observatories in the UK and four overseas. The original observatory buildings were designed to accommodate larger instruments and as a result have become inefficient 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 Technical University (DTU) FGE fluxgate magnetometers for all of its variometers. BGS has developed a new low-cost enclosure which is currently used to house backup variometer systems at Lerwick, Hartland and Eskdalemuir. This type of enclosure is also used at the recently re-established observatory on the island of South Georgia. To quantify performance of the new enclosure, a comparison was carried out between the primary variometer (GDAS1) at Lerwick (which continues to use the old-style of building for instruments) 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 and low-noise environment for long-term magnetic recordings.

## 2. CONSTRUCTION

The foundations for the enclosure are formed from a shallow raft (0.5 m) of non-magnetic concrete (all materials were tested for magnetic 'hygiene' before construction). This construction provides adequate stability, providing the fluxgate sensor has a tilt-compensation system. The enclosure is fabricated from a two-layer fibre-glass wall with a 15 mm polystyrene core of insulation. This combination gives the structure strength and durability whilst still remaining light enough to transport by hand. 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. The fluxgate electronics and heater are located at the opposite end of the enclosure from the sensor to reduce interference and promote a more stable temperature gradient across the sensor block. The fluxgate sensor is mounted directly on the concrete raft through a gap in the insulation to de-couple any wind vibration on the main structure from the instrument. The external dimensions of the enclosure are: Height: 1.5 m, Width: 1.0 m, Length: 2.0 m (tapered sides to reduce wind vibration).

## 3. THERMAL STABILITY

Given the simple construction and materials of the enclosure, it is possible to calculate the thermal loss characteristics of the system. The thermal characteristics are dominated by a combination of conductive and convective (air change) heat losses. Radiation losses are negligible due to the low emissivity foil on all inside surfaces. The rate of heat lost due to conduction ($dQ_c/dt$) 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 (the R-value for the insulation board was provided by the manufacturer's specifications).

$$\frac{dQ_c}{dt} = \frac{k_m A \Delta T}{x} \tag{1}$$

$$R_v = \frac{x}{k_m} \tag{2}$$

$$R_v = R_{v1} + \ldots + R_{vn} \tag{3}$$

***Table 1 – Total Thermal Resistance Value***

| Material | Usage | x (mm) | $k_m$ (W/mK) | $R_v$ ($m^2K/W$) |
|---|---|---|---|---|
| Fibre-glass | Wall | 03 | 0.040 | 0.075 |
| Polystyrene | Wall | 15 | 0.030 | 0.500 |
| Fibre-glass | Wall | 03 | 0.040 | 0.075 |
| Insulation board | Wall & floor | 75 | - | 3.450 |
| *Total walls:* | - | *96* | - | *4.100* |
| *Total floor:* | - | *75* | - | *3.450* |

The total thermal transmittance (Ut) for the enclosure construction is the reciprocal of the total thermal resistance (0.243 W/m2K and 0.290 W/m2K for the walls and floor respectively). The thermal transmittance values allow calculation of the combined conductive losses (equation 4). The heat lost via convection or natural ventilation ($dQ_v/dt$) 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).

$$\frac{dQ_c}{dt} = U_t A \Delta T \tag{4}$$

$$\frac{dQ_v}{dt} = NVC_v \Delta T \tag{5}$$

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 (N), the total predicted thermal losses can be summarised in Table 2. A result of the low thermal losses (<140 W) is that a low-power heating system can be designed to run from lower voltages, simplifying many aspects of the enclosure design.

***Table 2 – Total Thermal Losses at 20 °C Internal, -10 °C External***

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

## 4. HEATING ELEMENT

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 tailored heater elements specifically for this application. The heating element comprises four Vishay 50 W (56 Ohm) thick-film power resistors mounted in parallel on 1.3 °C/W anodised aluminium heat sinks. The heat sinks are then mounted in a standard 19” aluminium vented rack with all magnetic parts removed. The use of standard parts simplifies fabrication and future proofs availability of components whilst keeping the cost low. Powering the heating element at 48 VAC (RMS), produces a maximum power output of 160 Watts. The magnetic susceptibility 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 without failure.

## 5. PID CONTROLLER

The enclosure temperature is regulated using a Eurotherm 2404 PID process controller. The controller proportions power to the non-magnetic heating element in the enclosure via a TE10S solid state relay (SSR), and step down (220 VAC to 48 VAC) transformer (Figure 1). The TE10S relay ensures zero-voltage switching to ensure that the supply is switched on and off at zero points in the AC cycle. Zero-voltage switching prevents harmonics of the supply frequency being generated (a common source of noise) and also extends the operating life of the heater element by reducing high-frequency currents. For optimal performance, the PID control parameters are tuned, on installation, to the operating environment and response time of the system. The Eurotherm 2404 does this using a tuning cycle that forces the temperature in the enclosure to oscillate, allowing it to determine the ideal PID settings [2]. The 48V AC supply is chosen for safety to provide Separated Extra Low Voltage (SELV) protection from electric shock [1]. SELV permits un-armored power cables, due to the low voltage and electrical isolation provided by the transformer. This relaxes the power cable specifications and prevents introducing magnetic contamination associated with steel armored cable.

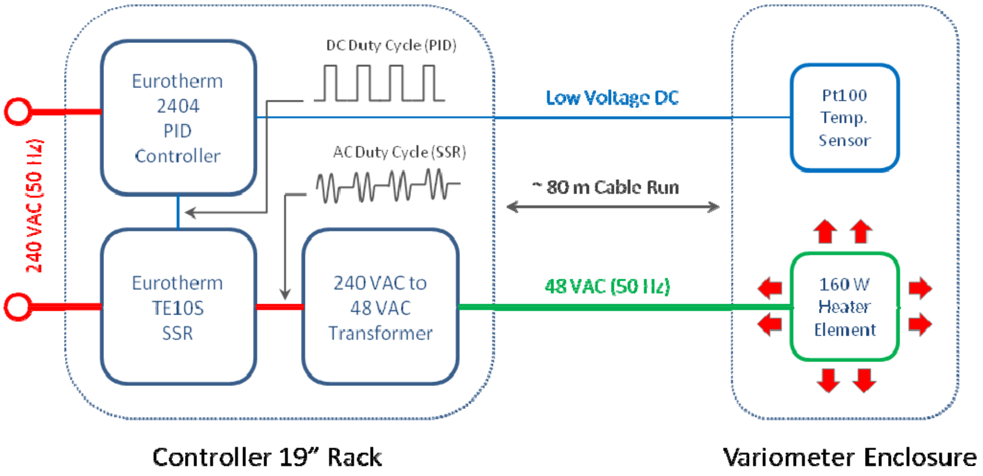

*Figure 1 –Temperature Control System for Enclosure*

## 6. PERFORMANCE

To assess the performance of the enclosure, both the short-term and long-term temperature stability of the system have to be considered. Figure 2 is a statistical view of the temperature stability of the new enclosure. The histogram shows 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 chosen set-point. This was during a period where, the average external daily range was 4.2 °C and the maximum daily range was 11.0 °C.

To quantify the quality of the new variometer enclosure (GDAS2), a comparison of the final data was carried out using the primary recording system at Lerwick observatory (GDAS1), with the assumption that this is a low-noise and stable (temperature & baselines) reference system. Comparing the variometer data in this way gives a measure of the total system performance taking into account any possible sources of contamination, noise or instability of the new enclosure. Figures 3 show the final data quality of this system compares well to the primary system with over 95% of minute samples from 2011 differing by less than +/- 0.5 nT in the Horizontal (H) and Vertical (V) components and +/- 0.5 arc-mins in Declination (D).

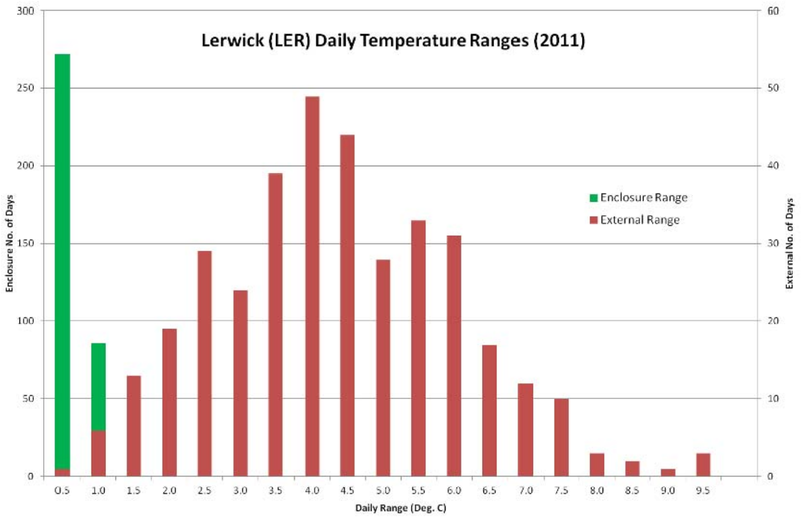

*Figure 2 –Daily Temperature Stability of New Enclosure for Lerwick (2011)*

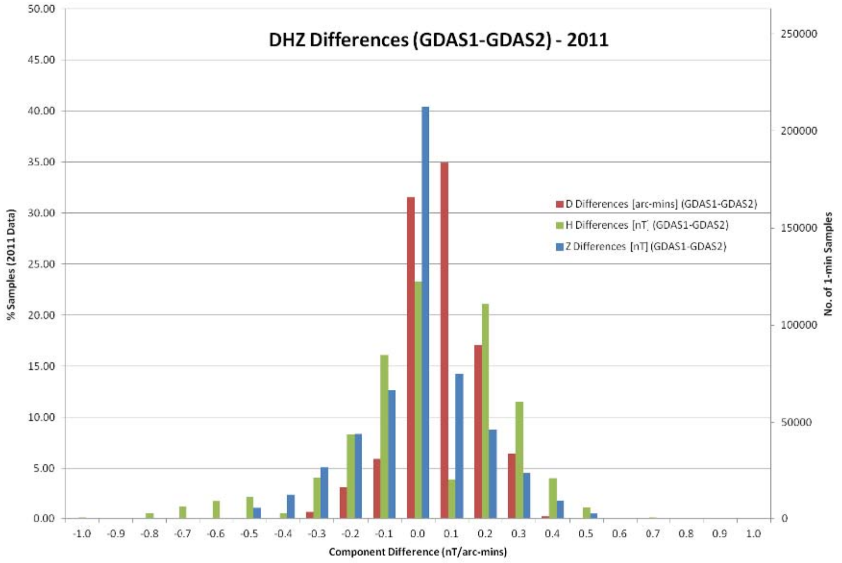

*Figure 3 –Comparison of Primary & New Enclosure Variometer Systems for Lerwick (2011)*

## 7. CONCLUSIONS

In general, tilt-compensated fluxgate 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 excessive tilt in locations where the soil is particularly soft, and this was briefly seen at Lerwick when a fault developed with the sensor tilt-compensator; a situation that would not typically affect more traditional installations.

Experience from operating the temperature control system shows the PID controller typically drives the heating element with a duty cycle of between 30-60 % over most of the year and has always been able to deliver sufficient power over the coldest periods. This equates to 50-100 Watts nominal power consumption which agrees well with the modelled thermodynamic performance of the system and the observed temperature variations (external) for 2011 at Lerwick. Due to the low thermal mass of the enclosure, temperature over-ranging can occur in the summer, but this could be reduced by adding more thermal mass to the system by banking earth around the enclosure. The data quality analysis confirms that the low-cost enclosure successfully provides a low-noise environment for making high quality magnetic recordings and that any long-term temperature variations are being adequately removed by the baselines used to produce the final data.

## 9. REFERENCES

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

[2] Eurotherm. (2004): "Eurotherm 2404 Installation & Operation Handbook, Issue 10.0".