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Instrumentation

BMR photoelectronic magnetographs

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New magnetic observatories in Australia are being equipped with commercial digital fluxgate magnetographs. However, where appropriate buildings and classical instruments already exist, devices designed and developed by the Bureau of Mineral Resources (BMR) (the MPE-1, horizontal and the MPE-2, vertical), are being added to provide visual charts and digital records. MPE work on the force-balance principle: when the earth's field varies, the couple exerted on a suspended magnet is counteracted by a couple from an opposite artificial field. The latter is produced by a null-detector/electronic-servo system, and the servo voltages are measures of the field variations.

The first MPE designed by BMR have been based on the QHM for horizontal components, and the La Cour Godhavn Z balance for vertical intensity. But in principle the servo system could be fitted to any suitably modified classical variometer. Two MPE systems have been operated at Mawson and Macquarie Island Observatories since 1984. Results show that they have resolutions and noise levels better than 0.2 nT, and their long-term stabilities are as good as those of the La Cour variometers they have replaced. At present they have no temperature compensation, but it is an easy matter to provide magnetic (or electronic) compensation. The main engineering features of the design follow.

A lateral effect photodiode senses the position of the light beam reflected from the magnet mirror. Unlike split photocells, this device gives a differential current output which is linear with respect to the deflection of the light spot. Several centimetres of active surface length ensure a wide dynamic range and keep the feedback loop operating for relatively large magnetic deflections.

A high-brightness LED is used for the light source. The peak emitted wavelength at 660 nm is visible for ease of setting up, and is less than 30% smaller than the peak response of the photodiode which lies near IR at 880 nm. The main advantage of a LED light source, however, is its ability to be switched rapidly, so permitting the light beam to be chopped. A chopping frequency of 220 Hz allows the input amplifier stages to be a.c. coupled, thereby eliminating the effects of drift and low frequency noise. After amplification, a synchronous demodulator converts the signal to d.c. The optical gain is kept constant by an internal feedback loop which controls the LED brightness. The electronic gains within the main feedback loop are all tightly controlled; so the overall loop gain remains constant and the closed-loop response is predictable.

An integrator is included in the forward path of the feedback loop to ensure that the magnet remains in a true null position (i.e. a Type 1 control system with zero steady-state error) for any field within the instrument's range of plus or minus 1000 nT around the baseline field. The QHM and Z-balance possess a very underdamped second-order transfer function ($Q > 100$). When this is combined with an integrator, the resulting third-order system has a very low stability margin when feedback is applied.

The problem was to design a system which remains stable for a loop gain ranging from zero (at turn on) to a value sufficiently high to give the desired closed-loop response, and to tailor this response so that the system is well-behaved for step field changes; for example, when a calibration pulse is applied. The frequency response must also remain high enough to follow the normal field variations. A complication lies in the fact that the response of a QHM or Z-balance is determined by its magnet and suspension characteristics, and may vary from unit to unit. Furthermore, the natural period of a given QHM varies inversely as the square root of the field component along the magnet axis. At a given location, the magnet is oriented at right angles to the field component being measured, so the natural period depends on location and orientation.

The feedback loop is stabilized by incorporating two lead-lag compensation networks. The compensation time constants were calculated to ensure stability at low gain even by a hypothetical mechanical damping factor of zero. It can be shown that this can be achieved if the compensation time constants are set proportionally to the magnet's natural period. When initially setting up at a new location or in a new orientation, the natural period is measured and four equal resistances are adjusted accordingly. Thus the closed-loop transfer function is normalized with respect to the magnet's natural period. The compensation networks and loop gain were designed such that the damping factor of the complex closed-loop system poles is about 0.7, so ensuring no overshoot or ringing in the transient response. For a QHM having a natural period, T s, the 10–90% rise time in closed loop is 3.2T s and the -3 dB frequency response is approximately 0.8/T Hz.

The dynamic range of the instrument is determined by the voltage swing available from the amplifiers in the feedback loop, and by the overshoot to a step input which occurs after the second compensation stage (in the feedback network and therefore not apparent at the output). The loop gains have been distributed such that these factors limit the steady-state range to plus and minus 1000 nT around the initial baseline field, and the maximum input field step is limited to 770 nT from the baseline field. The gain and phase margins (measures of stability), which are also determined by the design of the compensation networks, are 19.3 dB and 44° respectively. Work is continuing on an improved amplifier design and electronic temperature compensation.

The Flinders array magnetometer

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The use of arrays of magnetometers in geomagnetic deep sounding studies has two major advantages. The first is that a large area can be covered quickly, reducing the need for repeat visits, which is particularly important for terrains with difficult access. The second advantage is the opportunity to analyse single events of favourable polarization recorded simultaneously over a large area.

Array magnetometers should: be cheap, such that 20 or 30 can be constructed with a modest budget; be robust and small, for easy installation; have low power consumption and a data capacity large enough to allow some 3 months of unattended data recording; and have digital data so that the whole recording period will be available for rapid processing and analysis.

The first array magnetometer, of which more than 100 are now in use was developed by Gough and Reitzel (1967). It has proved to be highly successful and has been mainly responsible for the upsurge in geomagnetic deep sounding studies in the past decade. The Gough–Reitzel magnetometer uses a classical design, with magnets suspended from torsion fibres and recording on photographic film.

Recent advances in digital electronics and microprocessors have made it possible to design a digital array magnetometer, using fluxgate sensors, for the same cost as the Gough–Reitzel magnetometer. Such an array magnetometer was designed and built at Flinders University (Chamalaun & Walker 1982), and 25 magnetometers have been used in seven array studies over the last 4 years.

The Flinders magnetometer is a self-contained sealed unit (60 cm × 20 cm) which uses three orthogonal fluxgate sensors. Power consumption is reduced by careful selection of components, and by switching the unit off between measurements. The signal is converted by an analog-digital (A/D) converter pair. The heart of the unit is a microprocessor which controls the data acquisition sequence, applies a data compression algorithm, and writes the data from memory to a cassette tape. Using a 1 min sampling interval, data are written in 1 h blocks every hour, and the total recording period is 100 days. The sampling rate is switchable between 10 s and 1 min and can be varied further with alternative software. Although absolute calibration is probably not better than ± 80 nT, the full field values for each sensor are recovered from the data. Hence the instrument need not be orientated in the field except for verticality. At present the instrument is operated with 1 nT resolution; has a noise level of less than 0.5 nT; and, when buried, a drift of less than 5 nT per 30 days. Data loss arises mainly from the tape-recorder, but is generally less than 4 or 5 h in 100 days.

Currently a new prototype is being designed, which will have: solid state memory, for greater data integrity; a 'cmos micro', with much reduced power consumption, and greater (8k) program capacity; a programmable clock for added flexibility in varying sampling rates; a 16 bit A/D converter to reduce chip count; and ring cores to improve signal-to-noise ratio. As the cost of memory chips is falling rapidly, the overall cost of the magnetometer is expected to be about the same as the current model, while retaining the same capacity (100 days at 1 min sampling rate). In addition the use of existing data sets and computer simulation is being investigated, together with the feasibility of changing the data acquisition method from one in which the sampling rate is constant, to one in which the sampling rate is varied according to the rate of change of the magnetic field.

References

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