A low-cost digital teslameter

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A low-cost digital teslameter

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Abstract. A very simple and reliable hand-held teslameter is described. The probe is a low-cost commercial Hall sensor chip. A voltage regulator and an LCD driver complete the circuit. A test solenoid is designed to provide a straightforward absolute calibration with an overall accuracy better than 1% up to 1 T.

1. Introduction

Magnetic fields must frequently be measured within a small volume. Typical examples are: (i) a thin gap between magnetic pole pieces; (ii) a small solenoid core; (iii) map tracing a highly inhomogeneous field.

For these purposes the classical low-cost method of the search coil (Whittle and Yarwood 1973) is obviously inadequate, and use of a more expensive Hall effect device is unavoidable.

Commercially available Hall effect teslameters have a price in the range from \$1000 up to \$10 000, depending on the performance. Typical accuracy of the less expensive devices is some per cent of reading, while few models offer the useful options of digital display and battery operation.

In this paper we describe a digital battery-powered teslameter that can easily be constructed at a cost of less than \$100, and a calibrating solenoid which provides an overall accuracy of 1% up to 1 T ($=1$ Wb m$^{-2}=10$ kG).

2. Instrument description

The block diagram is shown in figure 1 and the detailed circuitry in figure 2. The probe is a linear output Hall sensor (Sprague UGN 3501M). This chip has a built-in current regulator, I, that feeds the semiconductor sensing crystal, C, and a linear preamplifier, A, with differential output, variable gain and offset-null capability. The output offset is zeroed by adjusting the cursor position of the potentiometer P_0. The total resistance value P_0, sets the gain of the preamplifier as well as the span of linear output. The larger P_0, the smaller the gain and the wider the linear range.

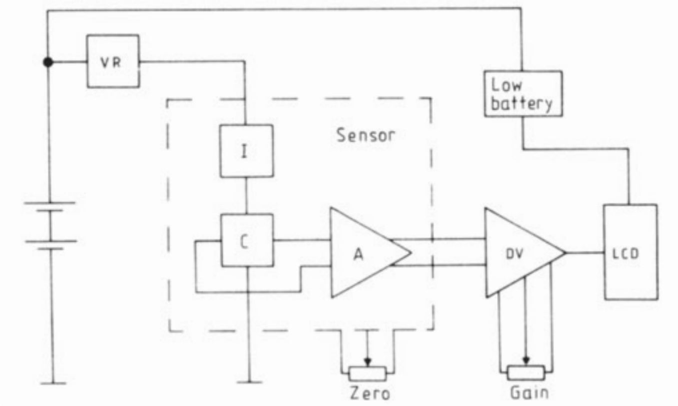

Figure 1. Block diagram of the teslameter.

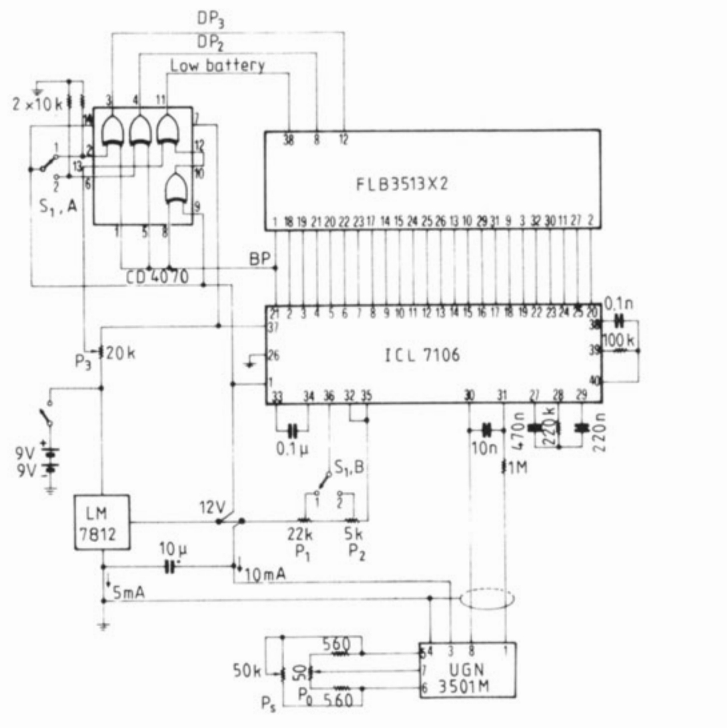

Figure 2. The detailed circuitry of the teslameter.

The probe is fed by a voltage regulator VR (National LM 7812), selected for low dissipation, that provides an output of 12.0 V with an input varying from 18 V to 13 V. The amplified Hall voltage is measured by a differential voltmeter DV (analogue-to-digital converter: Intersil ICL 7106) which drives a $3\frac{1}{2}$ digit LCD display (Fairchild FLB 3513X2).

The power is supplied by two 9 V dry cells, feeding a total current of less than 18 mA. By using alkaline batteries the continuous working life is over 24 h. An optional 'low battery' indicator gives a warning before the calibration of the device is lost. The voltage divider, P_3, drives one half of a quad exclusive-or gate (RCA CD4070) that switches on the low battery indicator when the voltage supply drops to 13 V.

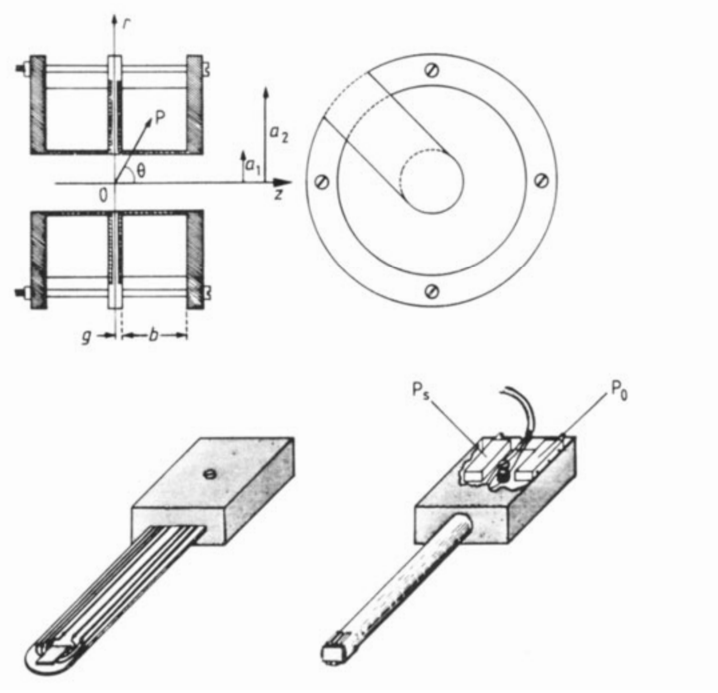

Figure 3. The calibrating solenoid and the transverse and axial probes.

The second half of CD4070 is used to drive the first or the second decimal point on the display (switch S_1, A). The teslameter sensitivity is controlled by the reference voltage V_c fed to pin 36 of the ICL 7106. Two V_c values can be selected (S_1, B) corresponding to output ranges of 0.2 T and of 2 T respectively. Sensitivity adjustment can be performed separately for the two ranges through the potentiometers P_1 and P_2.

The UGN 3501M is a 5 × 10 × 2 mm 8-pin dual in-line plastic package. By filing off the lower side of the plastic case and soldering the chip onto a 18 mm wide printed circuit board, one can obtain a transverse probe 1 mm thick.

Alternatively, by rounding off the chip edges and gluing it to a contact-carrying rod, a 11 mm diameter axial probe can be obtained (figure 3).

3. Calibration procedure

The teslameter sensitivity is given by the product $G\sigma$, where G is the DV gain and σ is the probe sensitivity (V T^{-1}). While G is a function of V_c only, σ depends mainly on P_0 but it also changes slightly from chip to chip.

With $P_0 = 1$ kΩ, a typical value for σ is 1.7 V T^{-1}. If the calibration is to be unaffected by changing the probe, a calibrating trimmer ($P_s \gg P_0$) must be inserted into the probe handle in parallel with P_0.

The trimmer P_s has to be adjusted once for each sensor. The potentiometer P_0, on the other hand, must be set more frequently because it balances the sensor offset which drifts with time and temperature. The distance between sensor and adjusting potentiometers P_0, P_s must be as small as possible in order to avoid output signal oscillations: 50 mm is suggested as the maximum distance.

The zero adjustment must obviously be accomplished with the probe placed inside a region where the magnetic field is negligibly small. the magnetic field of the Earth is small ($\simeq 5 \times 10^{-5}$ T) but much stronger stray fields may be produced inside the working area by ferromagnetic materials and by DC currents.

A safe procedure is to balance the offset with the probe inside a 'null-field box', made with few sheets of high permeability and low hysteresis alloy, such as mu-metal, Vacoperm or Supermalloy. Calibration is then performed by properly setting P_1 and P_2 in the presence of a known magnetic field.

4. The calibrating solenoid

We produced a magnetic field of the order of 0.1 T, known with an accuracy of 1% and highly homogeneous over an area of several mm^2, using the 'split solenoid' shown in figure 3.

The value of the magnetic field at the centre of this solenoid can be predicted precisely if the number of turns, N, for each coil winding, the current I and the geometrical parameters are measured with sufficient accuracy (Brechna 1969).

Compared with the more common iron-core electromagnets, air-core coils obviously provide a weaker magnetic field per unit of current, but they assure a better accuracy, because the uncertainty in the value of the core permeability is avoided.

Using reduced parameters $\alpha = a_2/a_1$, $\beta = b/a_1$, $\gamma = g/a_1$, where a_1, a_2, b and g are the coil dimensions defined in figure 3, we have, in SI units, for the axial field intensity at the centre of the coil:

$$B_z(0,0) = \frac{4\pi \times 10^{-7}}{\beta(\alpha - 1)} \frac{NI}{a_1} (f(\beta + \gamma) - f(\gamma)) \qquad (1)$$

where $f(x)$ is the non-dimensional function

$$f(x) = x \ln \frac{\alpha + (\alpha^2 + x^2)^{1/2}}{1 + (1 + x^2)^{1/2}}. \qquad (2)$$

The choice of the α, β, γ and a_1 values is not arbitrary however. The maximum B_z value for a given power dissipation is in fact obtained for $3.0 < \alpha < 3.2$ and $1.9 < \beta < 2.1$ (Brechna 1969), while the highest field homogeneity is achieved (Andrew *et al* 1966, Colavita and Bustos 1978) by satisfying a sort of 'Helmholtz condition': $2(\beta + 2\gamma) = 1.2(1 + \alpha)$, which is equivalent to $\tan\theta = 1.67$ (see figure 3, where P is the centre of the coil cross section). Assuming, for example, $a_1 = 10$ mm and $g = 2$ mm, the best choice is $a_2 = 30$ mm and $b = 20$ mm.

For a given solenoid geometry, the wire diameter (and consequently the value of N) is then chosen in order to obtain a total resistance R appropriate to the power supply to be used.

Using a 30 V–3 A power supply, we obtained a maximum $B = 80$ mT with a current $I = 1.7$ A using a 0.65 mm diameter wire, with $N = 1100$ turns and a total resistance of approximately 17 Ω.

Assuming a negligible error in the measured current I, and an uncertainty of 0.1 mm in the measurement of b, g and $2a_1$, then an accuracy of 99% for the calculated B_z value requires an uncertainty of less than 1 mm in the diameter of the outer coil.

To achieve the geometrical accuracy required, the coil holder must be carefully lathed from an aluminium bar. This will also provide good thermal dissipation for the 50 W power input required for the 80 mT field.

A precise outer coil diameter can be obtained if some attention is paid to obtaining uniform winding layers.

A slot for the transverse probe is provided by a slit disc spacer clamped between the coils which are fastened by brass screws (see figure 3).

The field homogeneity can be calculated analytically along the z axis (Brechna 1969) and numerically in the radial direction (Higbie 1978). In the last case a simple integrating subroutine can be used to evaluate the contribution of the single-turn symmetrical pairs to the field generated at a point $P(r, 0)$ and the result is obtained by summing over the N turns.

Figure 4 shows the calculated relative changes

$$\Delta B(r)/B = (B_z(r,0) - B_z(0,0))/B_z(0,0)$$

and

$$\Delta B(z)/B = (B_z(0,z) - B_z(0,0))/B_z(0,0)$$

for radial and axial displacements from the centre.

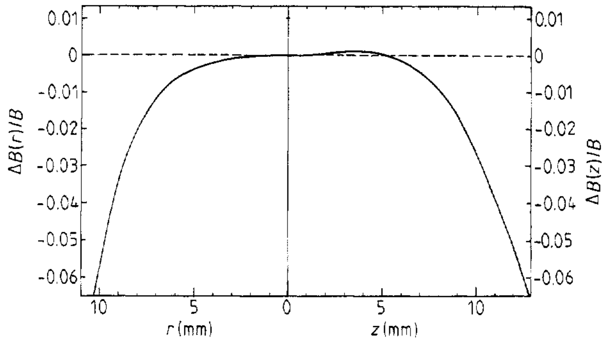

Figure 4. Theoretically calculated magnetic field changes for displacements from the solenoid centre along the axis ($\Delta B(z)$) and the plane of symmetry ($\Delta B(r)$), relative to the field at the centre (B).

5. Absolute calibration and linearity

Both the accuracy of the calibration provided by the solenoid and the teslameter linearity have been tested using a nuclear magnetic resonance apparatus (Alpha Scientific Labs model AL65).

The measured values, $a_2 = 30.7 \pm 0.5$ mm, $b = 20.0 \pm 0.1$ mm, $a_1 = 10.0 \pm 0.1$ mm, $g = 2.0 \pm 0.1$ mm and $N = 1100$

give a calculated field $B_c = 76.1 \pm 0.8$ mT at the solenoid centre for a measured current $I = 1.744 \pm 0.001$ A.

With the transverse probe inserted into the solenoid, the display reading is adjusted to the calculated value B_c. Then the probe is placed into the NMR apparatus whose magnetic field is adjusted to reproduce the same teslameter reading B_c.

At this point the exact value of the magnetic field B is obtained by measuring the resonant Larmor frequency $F_0 = \gamma_P B = 42.577$ B MHz T^{-1} using an accurate frequency meter (Hewlett Packard 5314 A). From the measured value $F_0 = 3.219$ MHz we obtain $B = 75.6$ mT, corresponding to a calibration error $(B_c - B)/B = 0.7\%$.

A test of the linearity is shown in figure 5. Here the magnetic field values B read on our teslameter (and on the RFL model 902) are plotted against the values B_{NMR} measured with the nuclear magnetic resonance.

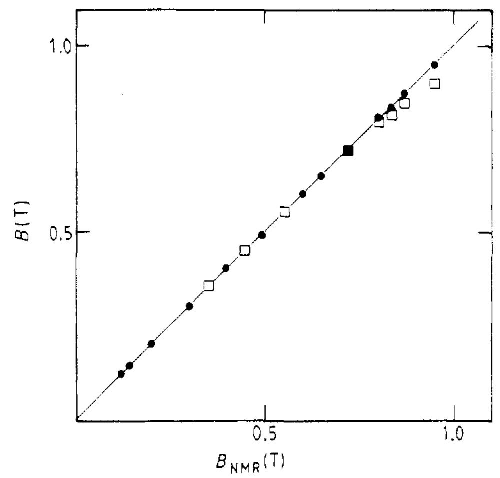

Figure 5. The teslameter readings, B, plotted against the values measured with the nuclear magnetic resonance, B_{NMR}. ●, our device; □, RFL model 902.

The sensor used in the present device (Sprague UGN 3501 M) has been chosen from several types of commercially available low-cost sensors. Other linear sensors (such as Honeywell 91SS12, Siemens SAS231 W, OST HR 270, Sprague UGN 3501 T) have lower sensitivity and/or smaller linear range and/or a higher temperature coefficient and/or larger offset output. Nevertheless all these sensors can be used to build a cheap teslameter with an accuracy of some per cent.

Our device performance can be summarised as follows: the long-term drift (within 24 h) is less than 1%, the thermal drift (in the range 15–40 °C) is less than 0.2% °C^{-1}, the non-linearity (up to 1 T) is less than 0.5%, the absolute accuracy provided by the solenoid is better than 1%, and, finally, the warm-up time is less than 10 min.

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A low-cost, versatile data reduction scheme for channel-plate detectors

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Abstract. We describe a simple and flexible counter interface, which can reduce the typical eight-bit position information of commercially available channel-plate detectors to a smaller number of counting channels. The number and width of these channels may be chosen arbitrarily under software control, according to the experimental requirements. It is demonstrated that fast data processing is then possible using a standard personal computer.

1. Introduction

Angle-resolved charged particle spectroscopies have become important surface analytical tools in recent years. All of them generally suffer from the conflicting requirements that (i) both energy and angular resolution should be chosen to be as good as possible, (ii) the number of particles registered must be large enough to be statistically significant, (iii) the measuring time should be as short as possible to maintain a low level of surface contamination, and (iv) the dose of primary particles frequently needs to be minimised to avoid surface damage problems. There is thus a need for efficient particle counting systems.

One solution for the problem is to use a position-sensitive particle detector of sufficient size at the analyser output, instead of the 'traditional' combination of a narrow exit slit and a single channeltron detector. We have therefore modified an ESCALAB photoelectron spectrometer (Vacuum Generators Ltd), which is used in our laboratory for angle-dependent spectroscopy, by insertion of a commercially available position-sensitive particle detector (Surface Science Laboratories, Inc.). This detector arrangement† fully exploits the linear energy-dispersive image formed in the exit plane of the analyser. Essentially it consists of stacked chevron microchannel plates which amplify the incoming signal and output onto a two-dimensional resistive anode encoder. The position of arrival of a charge cloud on the two-dimensional resistor is determined from the ratios of the charge pulses arriving at the four corners to the total charge collected by the resistor. The corresponding position computing electronics‡ supply a strobe pulse and the two-dimensional position signal in both digital (eight-bit resolution in each direction) and analogue output. While the digital outputs are generally used for data processing, the analogue outputs serve for monitoring purposes, e.g. to check the optimum sample alignment (with respect to the maximum count rate focused onto the channel plates) on an oscilloscope.

† Surface Science Laboratories model 3390, open-face sensor with 25 mm diameter microchannel plates and resistive anode.
‡ Surface Science Laboratories model 2401, high-speed position computing electronics. The input preamplifiers are optimised to high speed (dead time 3 μs).

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