An electromagnetic micrometer to measure wire location inside an ATLAS MDT drift tube

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Abstract

This short memo reports on an electromagnetic system for measuring the wire position inside an ATLAS MDT drift tube with a 2 micron accuracy.

1 Introduction

One critical parameter in the Atlas muon spectrometer is the accuracy on the location of the wires. For optimal performance the wires have to be centered with respect to the endplug outer reference surface to better than 10 μm RMS in both projections.

A simple and cheap system called EMMI (ElectroMagnetic MIcrometer) has been built. It provides a measurement of the wire position by means of electromagnetic pickup sensors.

2 Principle of operation

The principle of operation of the EMMI is shown in figure 1. If an alternating current $i(t) = i_0 \cos \omega t$ is circulating in a wire, the electromotive force $\mathcal{F}$ induced on a rectangular single-winding coil of surface $a \times b$ placed at an average distance L from the wire is given by[1]:

$$\mathcal{F} = \frac{2\omega i_0 \sin \omega t}{c^2} \cdot a \cdot \ln \left(1 + \frac{b}{L - b/2} \right) \ . \tag{1}$$

If two such coils are placed around the wire at a distance $L - \mathrm{d}$ and $L + \mathrm{d}$ respectively, the difference $\Delta\mathcal{F}$ between their electromotive forces is:

$$\Delta\mathcal{F} = \frac{2\omega i_0 \sin \omega t}{c^2} \cdot a \cdot \ln \left(1 + \frac{2b\mathrm{d}}{L^2 - (\mathrm{d} + b/2)^2} \right) \ . \tag{2}$$

For displacement d much smaller than b and L, equation (2) is very well described with a linear relation (see figure 1):

$$\Delta\mathcal{F} = \Delta\mathcal{E} \cdot \sin \omega t \ , \ \Delta\mathcal{E} \approx \frac{4\omega}{c^2} \cdot \frac{ab}{L^2 - b^2/4} \cdot \mathrm{d} \ . \tag{3}$$

For measuring the displacement of the wire from its nominal position inside a tube the following procedure is used:

a) Two coils are mounted in a fixed position with respect to two V-shaped precision supports for the endplugs' precision reference surfaces;

b) The tube is rotated around the endplug axis;

c) The amplitude $\Delta\mathcal{E}$ is recorded at eight equidistant angular positions;

d) The wire offset is identified by the amplitude of the variations of $\Delta\mathcal{E}$.

[1]All formulae are in c.g.s. units.

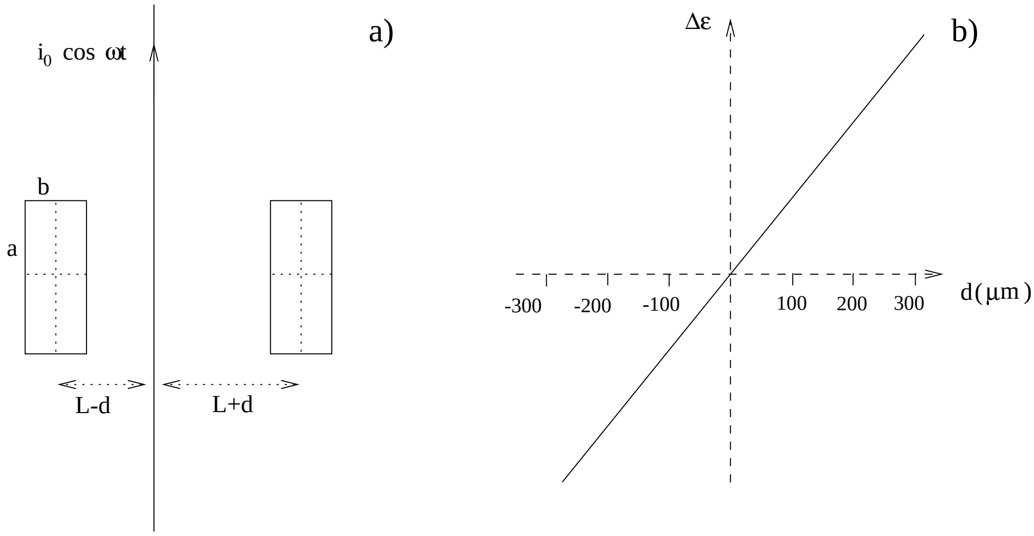

Figure 1: Principle of operation. a) Setup (a = 10 cm, b = 2 cm, L = 3.5 cm); b) Response for d much smaller than b and L.

In order to maximize the sensitivity of the EMMI, both the sinusoidal current amplitude and frequency have to be as large as possible.

The amplitude is limited however to approximately 100 mA if the wire temperature should not rise by more than 10 degrees[2].

The sinusoidal current circulating on the wire induces currents in the tube but these systematic effects were found to be negligeable for frequencies lower than 500 Hz[3].

3 The coils and the preamplifier

The sensors used are multi-winding air-coils. Assuming $i_0 = 75$ mA, $\nu = 235$ Hz, rectangular coils (single winding) of size 10×2 cm^2 positioned at an average distance of 3.5 cm from the wire, the expected signal given by equation (3) is

$$\Delta\mathcal{E} = 79.3 \text{ pV/winding}/\mu\text{m of wire offset from endplug center .} \tag{4}$$

This signal is very small, but increases linearly with the number of windings per coils. However, the preamplifier noise figure limits the maximum signal-to-noise ratio that can be reached. The first preamplifier stage uses the very low noise instrumentation amplifier INA103 from Burr-Brown, that provides the best noise performance for source resistances of the order of 200 ohms. With a 330 μm copper wire on a 10×2 cm^2 plexiglass core, this value is reached with 1600 windings, giving a signal of 127 nV/μm.

The preamplifier first stage provides a $\times 1000$ gain. It is followed by a filter with a passband of 170 to 1700 Hz and by a 50 Hz notch. A $\times 8$ gain amplifier, a filter equivalent to the previous one and a 100 Hz notch complete the amplification box.

The total gain at the working frequency[4] (235 Hz) is 69.75 dB.

4 Signal extraction

In order to measure the $\Delta\mathcal{F}$ (phase and amplitude) a lock-in amplifier has been used. This technique allows the extraction of a signal from a large background when there is fixed phase relation between the unknown signal and the modulating oscillator.

The measurement time depends on the signal-to-noise ratio, and for the system described in this memo is below one second per point.

[2] Measurements on the wire temperature rise were performed with a 1 m long MDT in still air. The temperature was measured at thermal equilibrium.

[3] For more technical details on the working principles please refer to [1].

[4] The working frequency was choosed to be lower than 500 Hz and not a multiple of 50 Hz.

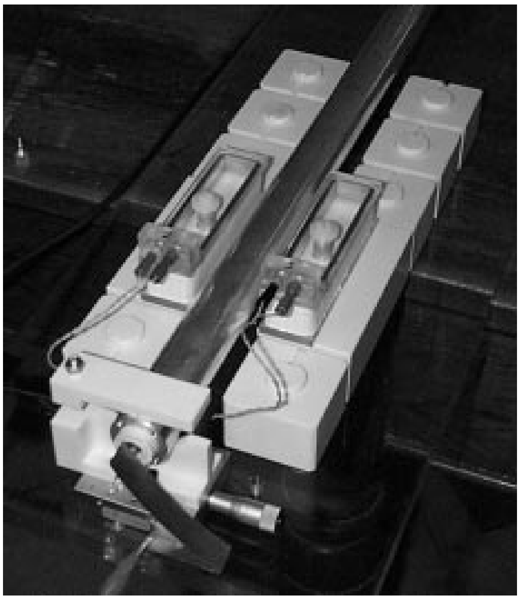

Figure 2: The EMMI prototype. The tube support (the diamagnetic "V") mounted on a micrometric slide and the two coils are visible in the picture.

5 Test setup

The prototype of the EMMI is shown in figure 2. Two air coils were positioned on the two sides of the tube at an average distance of 3.5 cm from the wire, 5 cm away from the endplug.

The tube was held in place by means of two diamagnetic V's mounted on two micrometric slides, used to position it symmetrically between the coils.

The wire was connected to a function generator [2] providing the 235 Hz sinusoidal modulation via a 50 ohm resistor. The signal available at the resistor ends was used to monitor the current circulating on the MDT wire.

The differential output from the coils was preamplified and sent to a quadrature lock-in amplifier [3] providing a measurement of both signal amplitude and phase.

6 Measurements and results

The EMMI was tested using 30 cm long MDT's especially built with the wire displaced from the endplug center by fixed quantities, from 5 μm up to 100 μm, and parallel to the tube axis (with some exceptions, see below).

Each tube had eight 3 mm diameter holes at both ends, one every 45°, a few centimeters away from the endplugs. These holes allow an independent measurement of the wire position by means of a microscope[5].

The correlation between microscope and EMMI measurements is shown in figures 3 and 4. Different kind of tubes were measured:

- Standard tubes;
- Plastic tubes;
- Standard tubes with tilted wires[6];
- Standard tubes with azimuthal thickness variations[7].

The displacement of the points from the fit gives a measure of the system resolution, found to be approximately 2 μm. There is no apparent difference in behaviour between the different kind of tubes, suggesting that the wire position measurement is independent on tube effects.

[5] The microscope has a single point resolution of the order of one micron.

[6] In these tubes, the wire forms an angle with respect to the tube axis up to half a mrad.

[7] These last tubes were obtained by partially immersing the tube in a 10% solution of sodium hydroxide. Each tube was closed at both ends to preserve the inner surface. In addition half of the surface - the part above the solution level - was covered with a silicon-based vacuum grease, to protect it from corrosive vapors. Corrosion rates of ~ 60 μm/h were obtained. Tubes with thickness variations as large as 100 μm were built.

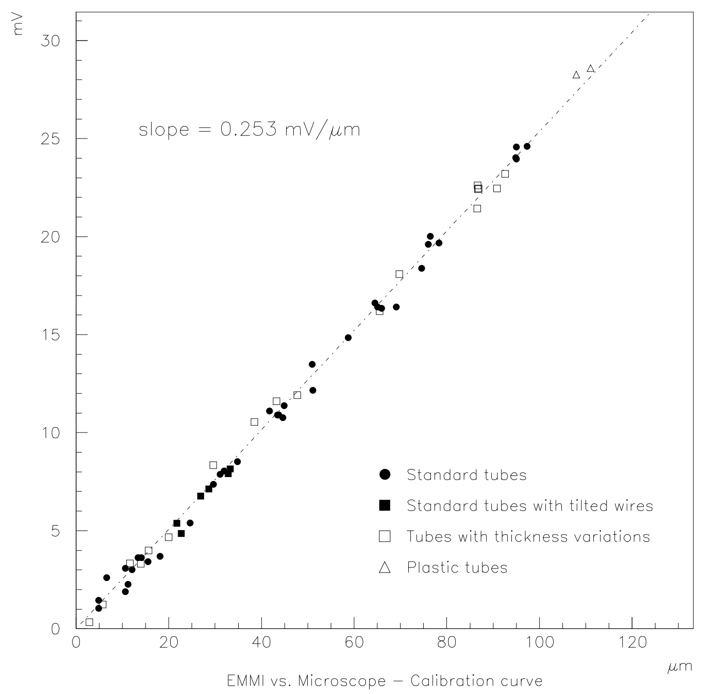

Figure 3: Correlation between microscope and EMMI measurements. The line (best fit to data) gives the calibration constant.

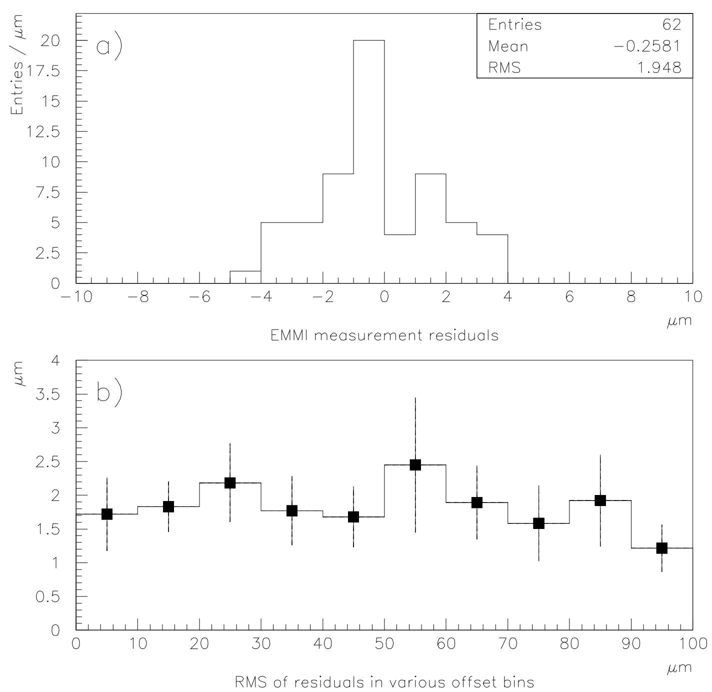

Figure 4: a) Residuals; b) RMS of residuals as a function of the wire offset.

7 Conclusions

A system able to measure the wire position inside an MDT drift tube with respect to the endplug outer surface has been built and found to be able to reconstruct wire offsets with an accuracy of 2 μm.

A measurement time of less than 1 second per point permits a full MDT check (both ends) in a time scale of the order of a minute.

More detailed studies on the electromagnetic micrometer will be presented in [1].

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References

[1] M. Cambiaghi, A. Cardini, R. Ferrari, G. Gaudio, Atlas memo in preparation.

[2] Philips PM 5134 function generator.

[3] EG&G Model 5210 lock-in amplifier.