M. Placidi, G. Renzler and S. Tazzari: AN INSTRUMENT FOR MEASURING MAGNETIC FIELDS IN THE RANGE 0.01 TO 20 GAUSS WITH PEAKING-STRIPS.

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1. INTRODUCTION

It is well known that a voltage signal of the type shown in fig. 1 (continuous curve) can be magnetically picked-up from a peaking-strip excited by a sinusoidal magnetic field of fixed frequency.

\[ V \]

\[ t \]

\[ \frac{T}{2} \]

\[ \frac{T}{2} \]

FIG. 1

1/T is the frequency of the exciting field. The amplitude of the peaks, besides depending upon from the peaker's mechanical characteristics\(^1\), is a function of the amplitude and frequency of the exciting field itself.

An external, constant magnetic field, oriented along the peaker axis, \( B_{\parallel} \), has the effect of displacing the peaks as shown by the dotted line of
fig. 1; let $\delta \tau (B_{\parallel})$ be the variation of their relative distance in time $\tau$, in the presence of $B_{\parallel}$. $\delta \tau$ is, with good approximation, a linear function of $B_{\parallel}$.

An external, constant magnetic field normal to the peaker axis, $B_{L}$, has no effect on $\tau$ but affects both the shape and the amplitude of the peaks.

We propose an instrument for measuring the value of $\tau$, and therefore of $B_{\parallel}$. We will discuss its performance in connection with the measurement it was designed for, and namely the determination of the magnetic axis and asymptotes of the quadrupole magnets for ADONE. It is obvious, though, that the instrument can measure any kind of magnetic field within its range.

2. MEASUREMENT OF THE POSITION OF AXIS AND ASYMPTOTES OF A QUADRUPOLE MAGNET -

We recall that the magnetic field in a quadrupole at a distance $s = \sqrt{x^2 + y^2}$ from the magnetic axis $z$, has the following components:

$$B_x = ky; \quad B_y = kx; \quad B_z = 0$$

with constant $k$.

Therefore, in order to measure the position of the magnetic axis, or of an asymptote, to within $\Delta s$, it is necessary to measure a field component, $B_{\parallel}$, to within

(1) \[ \Delta B_{\parallel} = k \Delta s \]

and the time distance $\tau$ of 1 to within

(2) \[ \Delta \tau = k \Delta s \frac{\partial \tau}{\partial B_{\parallel}} \]

$\partial \tau / \partial B_{\parallel}$ is, for a given frequency $\nu$ and amplitude $H_M$ of the sinusoidal exciting field, a characteristic constant of the peaking strip. Its value, for our strips(x), is typically

(x) - The wire used was NILOMAG 771 $\mu$-metal, diameter 3.6 mils.
\[ \frac{\partial \nu}{\partial B/|} = (6.8 \pm 1.1) \mu s/\text{gauss} \]

when \( \nu = 1 \text{ kHz} \) and \( H_M = 5.5 \) gauss.

If we then take for \( k \) a value of 100 gauss/cm and we wish \( \Delta S \) to be \( 10^{-3} \) mm, we get, from 2),

\[ \Delta \tau = 6.8 \cdot 10^{-8} \text{ s} \]

In order to be able to extend the measurements to the maximum possible distance from the magnetic axis, it will also be necessary to minimize the effects of the transverse field component, which amounts to marking the measurement of \( \tau \) as much as possible independent from the shape and amplitude of the peaker pulses.

3. APPARATUS -

The block diagram and circuit diagram of the apparatus are shown in figs. 2 and 3 respectively.

A 1 KHz oscillator (T1, T2) and a current amplifier (T3, 4, 5) supply the peaker’s excitation winding with a current the peak value of which can be varied, up to \( \sim 50 \) mA (corresponding to \( H_M = 5.5 \) gauss), by means of \( P_6 \).

A pick-up coil picks-up the peaker pulses together with a sinusoidal noise at the excitation frequency. Since, because of the small dimensions of the coils, it is not possible to eliminate this noise directly, the pick-up output is fed into a band-stopping filter tuned on 1 KHz.

The filter also causes the pulses to be strongly derivated and it's output is fed into a 40 db amplifier (T6, 7, 8).

The amplifier drives a bistable circuit (T9, 10, 11) the switching occurring at the zero-crossing in order to strongly reduce time fluctuations due to shape and amplitude variations of the peaker pulses.

Input and output waveforms of the bistable circuit are shown in fig. 4.

The bistable is a Schmitt circuit polarized in the center of the hysteresis region, so that, after an initial transient (fig. 4a), its output is the one shown in fig. 4b. The width \( \Delta V_h \) of the hysteresis region can be varied by means of \( P_4 \).

The RC circuit that follows the Schmitt circuit is such that:

\[ RC \gg (t_2 - t_0) = T \]
TR_{12} \pm TR_{15} - Mounted on a common copper radiator

FIG. 3
The final average voltage across C is therefore

\[ V_{av} = \frac{1}{T} \left\{ V_2(t_1-t_0) + V_1(t_2-t_1) \right\} = \frac{t_1-t_0}{T} (V_2-V_1) + V_1 \]

using the notations of fig. 4.

\[ \frac{\partial V_{av}}{\partial t_1} = \frac{V_2-V_1}{T} = \frac{\partial V_{av}}{\partial \tau} \]

For our circuit

\[ V_2-V_1 = 15 \text{ Volts}; \quad T = 10^{-3} \text{ s}; \quad \frac{\partial V_{av}}{\partial \tau} = 1.5 \times 10^4 \text{ Volt/s} \]

A microammeter is connected, through two double D.C. emitter-followers (T12, 13, 14, 15) between C and a reference voltage source. Besides integrating again over any residual ripple, it measures the difference between \( V_{av} \) and the reference, the reading being proportional to \( (t_1-t_0) \) and therefore to \( B_// \).
The helipot \( P_2 \) allows the zero of the instrument to be moved over a wide range of voltages.

Power is supplied by two different sources, of which one, supplying \( T_6 \) through \( T_{15} \), stabilized to \( \sim 0.01\% \), the other stabilized to \( \sim 0.1\% \). The high degree of stabilization and the two double emitter followers are necessary since, taking \( \Delta \tau \) from 3, one has:

\[
\Delta V_{av} = \frac{\partial V_{av}}{\partial \tau} \Delta \tau \approx 10^{-3} \text{ Volt}
\]

and also, since \( V_{av} \approx 10 \text{ Volts} \)

\[
\frac{\Delta V_{av}}{V_{av}} \leq 10^{-4}
\]

The whole circuit, except the power supplies and the peaker excitation circuitry, is enclosed in a styrofoam box in order to reduce short term temperature fluctuations. Long term temperature drift if not very relevant since it can be corrected by means of \( P_2 \).

Switch \( C_1 \) enables the peak excitation current, and therefore the peak excitation magnetic field, to be measured on the microammeter.

The sensitivity of the instrument can be reduced by a factor of 10 or of 50 by means of switch \( C_2 \).

4. PERFORMANCE -

Let \( i \) be the current flowing through the microammeter. One has:

\[
\frac{\partial i}{\partial \tau} = \frac{\partial V_{av}}{\partial \tau} \cdot \frac{1}{f} = r + r_i
\]

\( r_i \) being the internal resistance of the instrument and \( r_p \) the resistance of \( P_1 \).

By proper adjustment of these values we obtained for our circuit the measured value:

\[
\frac{\partial}{\partial \tau} = 10 \mu \text{A/\mu s}
\]
Using a test magnet of known, variable field, curve o) of fig. 5, of i versus $B_\parallel$ with $B_\perp = 0$, was obtained. The slope is

$$\frac{\partial i}{\partial B_\parallel} = 68 \ \mu A/\text{gauss}$$

and stays constant up to about 30 gauss.

Repeating the calibration at different values of $B_\perp$ curves 1), 2), 3) of fig. 5 were obtained. The time jitter of the Schmitt circuit output was also measured as a function of $B_\perp$, and found to remain approximately constant, and compatible with the values we will later mention, up to about 1 kgauss transverse field. Beyond 1 kgauss it suddenly increases by a factor of about 10. The conclusion is that, up to 1 kgauss, the only effect of the transverse field is to lower the upper limit of the useful range of the instrument. Beyond 1 kgauss the lower limit is affected too.

To determine the lower limit of the range of the instrument experimentally, the value of the current $i$ was recorded over a period of 17 hours of continuous operation, after about 1 hour warm-up and, with $B_\parallel = B_\perp = 0$. The total drift was found to be $\sim 8 \ \mu A$, corresponding to an average slope of $0.5 \ \mu A/h$. The maximum short-term (10 m) fluctuation was $0.2 \ \mu A$, corresponding to $\sim 0.003$ gauss.

A $\pm 5\%$ variation of the A.C. supply voltage caused an output variation of $\pm 0.4 \ \mu A$, and a $\pm 1\%$ variation of the excitation frequency an output variation of $\pm 0.2 \ \mu A$.

If we assume that $4 \ \mu A$ is the lower limit of the sensitivity of the apparatus we obtain, with $B_\perp = 0$, the following results.

Useful range $\sim 0.006 + 30$ gauss

$$\Delta \tau = \frac{\Delta i}{\partial i/\partial \tau} \approx 4.10^{-8} \ s$$

This value of $\Delta \tau$ is slightly better than the one required by 5).

It is our opinion that a better stabilization of the d.c. supply voltages could still be useful.

We would also like to emphasize again that the quoted results are to be thought of as strongly dependent from the peaking-strip used. It is however our experience that it is not difficult to build peaking-strips that, on the average, have characteristics similar to the ones we mentioned.
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