A TURBINE DRIVEN ROTATING COIL MAGNETOMETER*

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Summary

A rotating coil magnetometer which utilizes an air turbine to turn the coil has been developed. Since the turbine rotor forms the mount for the coil, there are no shafts or gears. Thus, this magnetometer may be used to measure fields in locations inaccessible to more conventional rotating coil devices. The precision of the suspension of the turbine and the lack of mechanical vibration make it possible to measure transverse field components of the order of one milligauss in a field of one kilogauss. The sensitivity of the magnetometer is made independent of the rotational speed of the coil through the use of an electronic integrator. The coil and integrator circuit is used in conjunction with another system which allows the determination of the direction of the magnetic field being measured relative to a predetermined direction.

Introduction

Rotating a coil in a magnetic field has been a standard method of measuring static magnetic fields for many years. Devices based on this principle are simple, reliable, and, if reasonable care is taken in their design and construction, extremely accurate. There are, however, some drawbacks to this method. Among these are the necessity for accurate control of the rotational speed, the requirement that the drive motor be coupled to the coil through a shaft long enough so that the presence of the motor will not affect the field being measured—on large cyclotrons this can be troublesome—and, for some very low field applications, quite exotic brush designs to minimize electrical noise. Further, to measure the transverse components of a magnetic field requires, in many cases, very sophisticated electrical or mechanical design. We would like to describe here a field measuring device employing a rotating coil in which the difficulties just mentioned have been overcome.

Magnetometer

The first step in the development of this device was to employ an air-driven turbine to rotate the coil. By placing the coil within the turbine rotor, the need for coupling shafts and/or gear trains was eliminated. Thus, the device can be made very compact. In addition, either longitudinal or transverse components of a field may be measured by simply choosing the proper orientation for the coil axis. Figure 1 shows the coil and turbine assembly. The coil is wound on a ceramic form for dimensional stability. The proportions of the coil follow the criteria developed by Laslett[1] so that the coil measures the field at its magnetic center, independent of gradient to second order. The turbine rotor is made of linen-loaded bakelite. It rotates on berylium-copper ball bearings. Signal pick-off is accomplished through a standard Airflyte electronics assembly (their type B30143 slip rings and A30167 brushes) utilizing gold alloy brushes and slip rings. While these slip ring-brush assemblies possess excellent noise properties,[2] these are not crucial to the design. Not shown in this figure is a photo cell and mirror system which gives a pulse once per revolution of the coil.

Since a rotating coil does not measure the field directly but rather gives an output signal proportional to the rate at which the projected cross-sectional area of the coil on the magnetic field varies with time, the output signal of any rotating coil device will depend not only on the magnetic field but also the rotational speed of the coil. It is unlikely that a turbine for this application can be built that would have the speed regulation of a good synchronous motor supplied by a crystal-controlled oscillator. On the other hand, extremely high gain operational amplifiers have been available for some years. By connecting one of these in integrator configuration to the coil output, the output of the coil-integrator circuit can be made closely proportional to the flux cut by the coil over a range of speeds given by

$$\frac{10\pi}{\tau} \leq \omega \leq \frac{\pi R}{5L} \qquad (1)$$

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where τ is the time constant of the integrator, R is the input resistance of the integrator and L is the inductance of the rotating coil. Thus, with reasonable design, a range of operating rotational speeds several octaves wide may be had. For the device being described this range extends from 1800 rpm to well above 18000 rpm. Were it not for the necessity of removing the dc drift from the integrator, the low end of the range would be considerably below 180 rpm. This range is far greater than any observed speed variation of our turbine. Our normal operating speed range is ± 120 rpm centered around 4800 rpm.

In Fig. 2 a simplified block diagram of the coil-integrator system is given along with that of an additional system that allows us to determine the direction of the magnetic field being measured relative to a fixed direction.

Referring to the coil and integrator system, we have incorporated an additional amplifier in the circuit to allow range switching without disturbing the integrator time constant. With the amplifiers and part values shown, the three ranges are 0.1 gauss per volt, 1 gauss per volt and 10 gauss per volt. The "T" network of resistors bridging the integrator stabilizes the integrator against drift but, as mentioned before, raises the lower end of the frequency range.

The absolute error of the coil-integrator system is less than 0.5 per cent of reading on all but the highest sensitivity range where the absolute error is 0.5 per cent of reading or 3.5 milligauss, whichever is larger. While this accuracy is not particularly impressive in comparison with other rotating coil devices,[2] it should be pointed out that in our application, finding the median plane of a magnet, this accuracy is more than sufficient. For example, we can measure transverse components of a two kilogauss field of the order of 0.1 gauss to an accuracy of 0.01 gauss. Then we know these transverse components to one part in 10^5 of the longitudinal field. This is sufficient for the initial alignment of an accelerator. Furthermore, the accuracy of the device is determined mainly by the stability of the components in the feedback circuit, assuming the amplifier gain is large. Since the amplifiers used here have open loop gains of greater than 10^6, it is reasonable to expect that the ultimate accuracy of the device should be at least a part in 10^4.

Angle Encoding System

The second system on the block diagram utilizes the signal from the photo cell to start and stop a counter. This counter, labeled "P", counts a stable oscillator. After the "P" counter starts, the next negative going zero crossing of the signal from the integrator turns on a second counter, labeled "I", which counts the same oscillator. The next photo cell pulse stops both counters. The contents of the two counters serve to determine the phase of the integrated coil signal relative to the rotation of the coil. From this information the direction of the field may easily be obtained. If no interrogation of the system is made before the next photo cell pulse arrives, this pulse will clear the counters and the process will start again. Thus, a determination of field direction is made every two revolutions of the coil. With a fast data handling system, say an incremental tape unit, information as to field magnitude and direction can be acquired rather rapidly. In our system an IBM card punch is used for recording this information. The accuracy of the angle encoding system just described is about ± 1° against the range of speeds and magnetic fields we encounter and is completely adequate for our purposes.

Figure 3 shows the output of the integrator with the coil in a zero field region. It is indicative of the noise level of the system. The vertical calibration of the scope is 35 millivolts per centimeter. It should be noted that the major noise component is 60 cps. A vigorous search for ground loops would materially reduce this.

Figure 4 shows the output of the coil and integrator system while finding the transverse field components of a field with a gradient of 1000 gauss per centimeter. The transverse field component here is 1.3 gauss. The longitudinal field component is 1000 gauss. Any vibration of the coil at frequencies near the coil rotational frequency would be quite apparent under these conditions.

References

1. L. J. Laslett, Reports LJL1 and LJL2, Accelerator Development Department, BNL, 5 July 1954 (unpublished).
2. J. R. Mulady et al., Rev. Sci. Instr. 35, 1437 (1964).

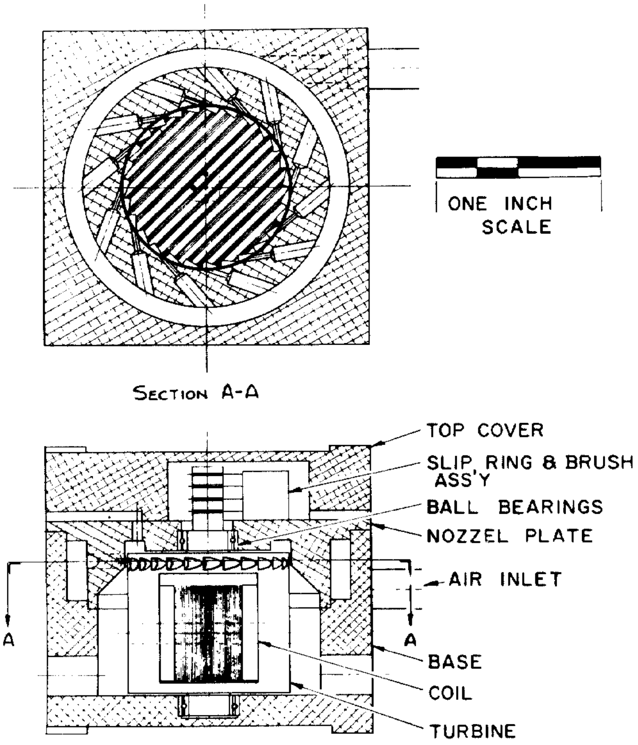

Fig. 1. Coil and turbine assembly.

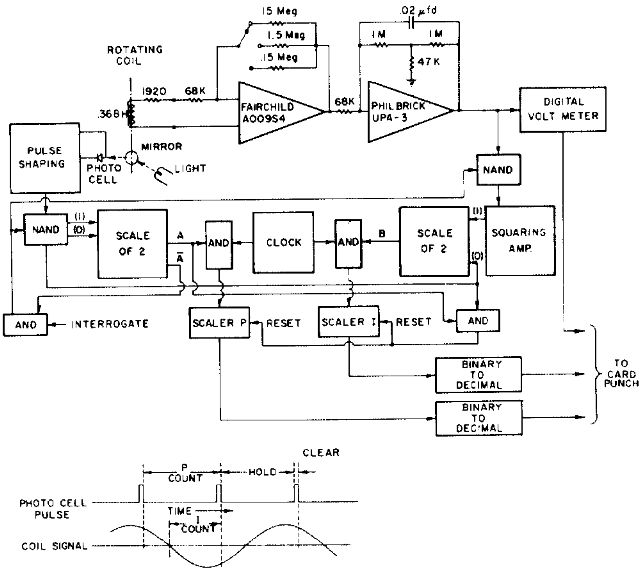

Fig. 2. Simplified block diagram of coil-integrator and angle encoding systems.

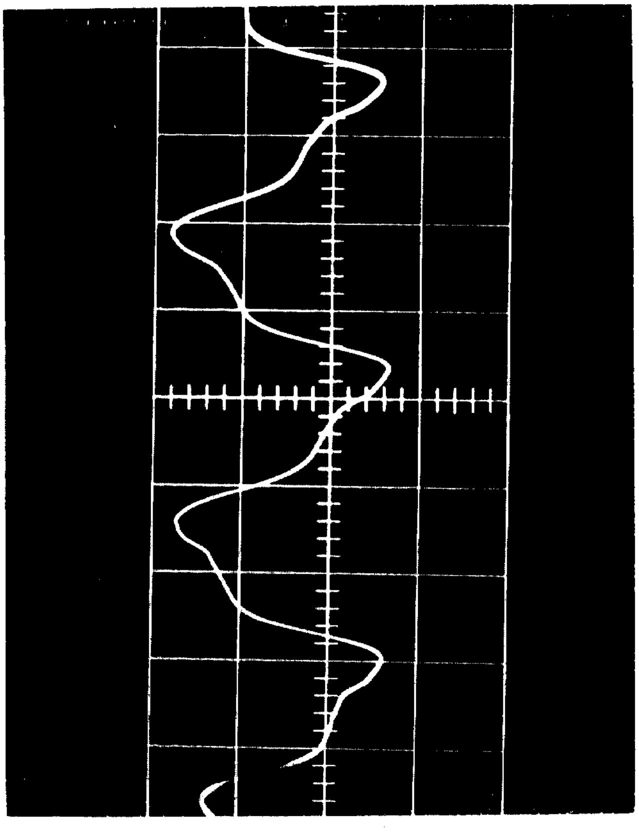

Fig. 3. Output of coil-integrator circuit with coil rotating in zero field region.

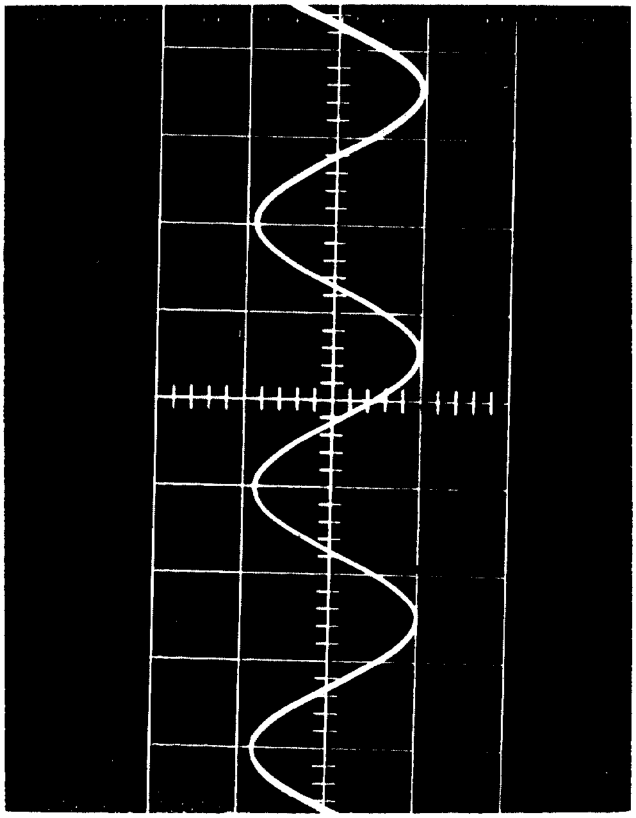

Fig. 4. Output of coil-integrator circuit measuring transverse component of one kilogauss field in high gradient region.