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IMAGE EFFECTS AND THE VIBRATING SAMPLE MAGNETOMETER

by Donald R. Behrendt and Donald E. Hegland
Lewis Research Center
Cleveland, Ohio 44135

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16. Abstract

Some anomalous effects observed in the output signal of the vibrating sample magnetometer have been investigated. The variations in amplitude and phase of the signal coil voltage are attributed to changes in the magnetic images of the sample in the pole pieces of the electromagnet due to changes in the permeability of the pole pieces. A set of eight signal coils was designed and built which eliminated the effects of the phase variations of the signal coil voltage on the output signal and which also reduced changes in amplitude of the output signal due to these image effects.

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Lewis Research Center

SUMMARY

Images of the sample in pole pieces of an electromagnet produce a spurious voltage in the signal coils of the vibrating sample magnetometer. The magnitude of this spurious voltage is dependent upon the degree of magnetic saturation of the pole pieces as this affects the strength of the images and their position relative to the sample and signal coils. In general, the spurious voltage is not in phase with the sample induced voltage. The superposition of these two induced voltages produces a field dependent amplitude and phase variation in the measured signal voltage which does not correspond to the true sample moment. It is demonstrated that a set of coils consisting of eight signal coils can be designed which reduces the effects of the phase variations in the output signal to a tolerable level and reduces changes in amplitude of the output signal due to these image effects.

INTRODUCTION

The vibrating sample magnetometer is used to measure the magnetic moment of a material by sinusoidally displacing the sample along a vertical axis while a magnetic field is applied along a horizontal axis. The resulting magnetization of the sample produces a dipole field which because of the periodic sample motion induces a time varying voltage in the stationary signal coils. The voltage induced in these coils should be proportional to the magnetic moment of the sample and the amplitude of its vertical motion. However, a spurious additional voltage may be induced in the coils by images of the sample in the pole pieces of the electromagnet and by eddy currents induced in these pole pieces. The magnitude of this spurious voltage changes as the permeability of the pole pieces changes. As the field of the electromagnet is increased, the permeability of the pole pieces decreases, the strength of the images decreases, and the images retreat farther into the pole pieces.

There will in general be a difference in the phase between the voltages induced by the sample and its images because of various losses in the pole pieces. As the image-induced voltage decreases because of an increasing applied field, the phase difference between total induced voltage and sample-induced voltage will decrease. This change in phase of the total signal voltage cannot be corrected by simply adjusting the calibration of the instrument to compensate for the change in response with applied field. A study was made to determine if a signal coil geometry could be developed that would reduce or eliminate the amplitude and phase changes due to the spurious image voltage. Such an arrangement of coils was found and is described in this report.

Weiss and Forrer (ref. 1) in an earlier paper discussed the effects of sample images in the pole pieces of the electromagnet. Stoner, Herbert, and Sill (ref. 2) have reported observing image effects using a vibrating sample magnetometer. They point out that these effects are present at low fields and that they can significantly affect the magnitude of the vibrating sample magnetometer output signal. Both Foner (ref. 3) and Case and Harrington (ref. 4) have reported finding no evidence of image effects in their experiments using the vibrating sample magnetometer. It is possible that variations in the relative locations of the sample and signal coils with respect to the pole pieces can account for these differences in image effects reported in the literature.

The instrument used in this investigation was built by a commercial supplier and was patterned after one designed and built by Foner (ref. 3). We have found large changes in the output signal of this magnetometer due to changes in image effects. These effects are observable even at small applied fields.

RESULTS AND DISCUSSION

The original coil geometry used in this investigation is shown in figure 1. Each coil of these transverse pole-tip coils shown fits tightly against a pole piece of the electromagnet. The response of the magnetometer was determined by using a high-purity polycrystalline iron sphere. For the coil geometry shown in figure 1, the response is shown in figure 2 (curve A). This particular sample of iron was saturated for applied fields greater than 1.0 tesla. If no image effects are present or if they do not change with applied field, the response of the magnetometer should be independent of applied field for a sample of constant magnetic moment; under the same conditions of no image effects, the response for an iron sample should show a small linear increase for fields above 1.0 tesla due to the high field susceptibility of iron; this is shown in figure 2 (curve B). The actual response using iron shows a rapid rise of more than 16 percent between 1.8 and 3.0 teslas. These data were obtained with the demodulator phase balance optimized at low fields. This anomalous response was reduced when the gap of the electromagnet was increased while the sample and signal coils were held fixed. This suggested that images of the sample in the pole pieces were responsible since increased distance between the sample and images would be expected to reduce the contribution of the images to the signal voltage.

A second and more serious problem encountered is that along with the increase in response the phase of the signal voltage was observed to change with applied field. The induced voltage in the signal coils depends on the displacement amplitude of the sample, on the magnetic moment of the sample, and on the image effects. The output signal of the magnetometer is made independent of the displacement amplitude of the sample by utilizing a reference voltage derived from capacitor plates attached to the sample rod. The response then depends only on the sample magnetic moment and image effects if any. The proper operation of the magnetometer requires that the reference voltage and the signal coil voltage be matched in phase. Because the phase of the signal coil voltage varies with applied field, this phase match cannot be maintained and large errors result. These phase variations can be attributed to changes in the strength and position of the sample images in the pole pieces and to changes in the eddy currents in the pole pieces produced by the moving sample.

Stoner, Herbert, and Sill (ref. 2) have made a theoretical analysis using a magnetic dipole sample and its images in two infinite-plane, parallel pole pieces for which they calculate the field distribution for two values of the permeability of the pole pieces. They show that the response of the transverse pole-tip coils should increase as the permeability of the pole pieces decreases. For the axial pole-tip coils shown in figure 3 their analysis shows that the response should decrease with decreasing permeability of the pole pieces. This agrees with both their experimental results and ours for these two coil configurations. By combining the voltages of the transverse and axial pole-tip coil sets (figs. 1 and 3), the response should depend less on the image effects since the changes in the two signal coil voltages will compensate one another. However, the additional sets of coils between the sample and pole pieces would require that the air gap of the electromagnet be increased and lead to an undesirable reduction in maximum field. This objection can be overcome by using two additional pairs of axial coils (the axial side coils), one pair on the positive x-axis and the other on the negative x-axis, as shown in figure 3. The observed response for this set of coils is similar to the transverse pole-tip coils in that their response increases with increasing applied field. The analysis of reference 3 indicates (figs. 8 and 9 of ref. 3) such coils should show an increase in response with decreasing permeability of the pole pieces in agreement with our observations.

Four pairs of coils, two pairs of axial pole-tip coils and two pairs of axial side coils, were made using 32 B & S enameled wire and installed on the pole pieces of the electromagnet. The four axial pole-tip coils were wound with an inside diameter of 1.27 centimeters (0.5 in.) and an outside diameter of 4.41 centimeters (1.73 in.) and were 0.635 centimeter (0.25 in.) thick. Each pair of coils was supported by placing them in holes drilled into 0.632-centimeter- (0.25-in.-) thick G-10 epoxy boards. Each of the G-10 boards was mounted flush against one of the pole pieces of the electromagnet. The two pairs of axial side coils were wound on forms having an inside diameter of 1.27 centimeters (0.5 in.) and an outside diameter of 3.81 centimeters (1.5 in.), each coil being 1.58 centimeters (0.625 in.) thick. The coils and forms were then mounted between the G-10 boards which contained the four pole-tip coils. The placement of these side coils relative to the sample and applied magnetic field is shown in figure 3.

The four axial pole-tip coils were connected in series in such a manner that their sample induced voltages were in phase. The same was done for the four axial side coils. The voltages from the two sets of four coils were then combined in parallel; a resistor, R_1, was added in series with the four axial pole-tip coils to reduce their sensitivity to that of the axial side coil combination as shown in figure 4. In order to produce an electrical zero near the geometric center of the eight-coil combination, each coil was shunted with a large value resistor. The electrical zero is the position of the sample between the coils such that vertical displacements of the sample (positive or negative displacements along the z-direction) decrease the output signal and displacements along either positive or negative x- or y-axies increase the output signal. By varying the resistor, R_1, in series with the set of axial pole-tip coils, the response could be made to rise or fall in the range of applied fields in which the large changes due to image effects were observed.

It has already been mentioned that the large image effects using the transverse pole-tip coils produced such large changes in the phase of the pickup coil voltages that the system was not accurate above 2.0 teslas. With the eight-coil combination the phase of the pickup coil voltage was almost constant, that is, the small variations in phase that do occur are not large enough to detune the demodulator.

The magnitude of the residual image effects for the eight-coil combination is shown in figure 2 (curve C). The transverse pole-tip coils alone showed an amplitude change of over 16 percent due to image effects. The combination of axial pole-tip and axial side coils shows a smaller change of less than 4.5 percent over the same field range.

In order to investigate the low field response of the eight-coil combination, the iron sample had to be replaced since the iron is not sufficiently saturated at these low fields. A small coil of wire 0.955 centimeter (0.375 in.) in diameter by 0.955 centimeter (0.375 in.) long was attached to the sample rod. The constant magnetic moment produced by passing a direct current through the coil could be used to examine the response at low fields. For fields above 1.2 teslas the response was determined by using the coil in conjunction with the iron sample along with published values of the high field susceptibility of iron (ref. 5). Figure 5 shows the response as a function of applied field for the eight-coil combination. This curve shows the relative change in the calibration constant of the system with applied magnetic field relative to zero applied field. Even at relatively small applied fields the image effects cannot be neglected. At 0.7 tesla the response is increased by 0.1 percent over its zero-field value. By using a calibration constant which is a function of the applied field, the small residual image effects can be compensated to yield an overall accuracy of ±0.2 percent for the system.

Lewis Research Center,
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Cleveland, Ohio, November 27, 1970,
129-03.

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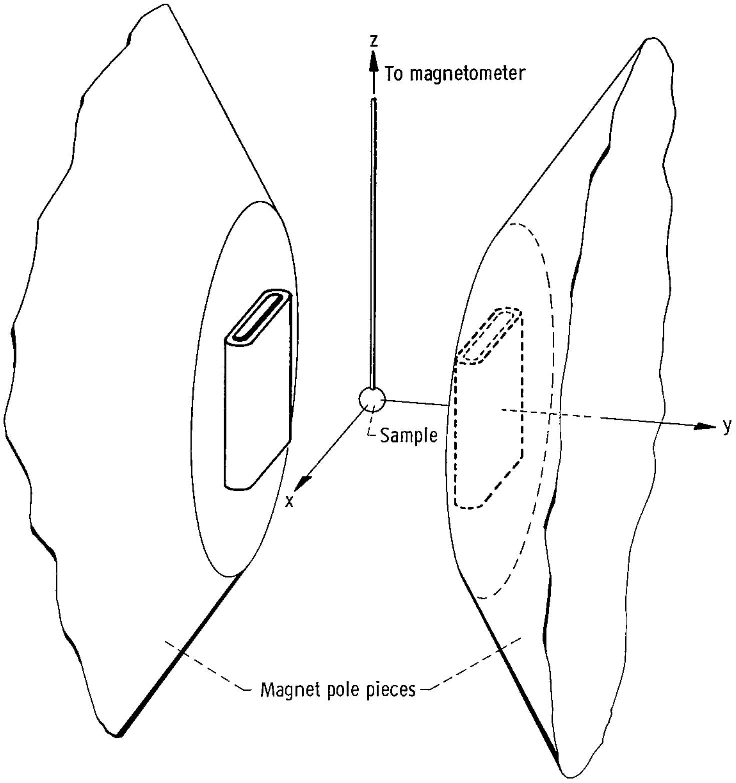

Figure 1. - Original coil geometry. Transverse pole-tip coils exhibit increase in signal voltage as pole pieces become saturated. Sample located at origin.

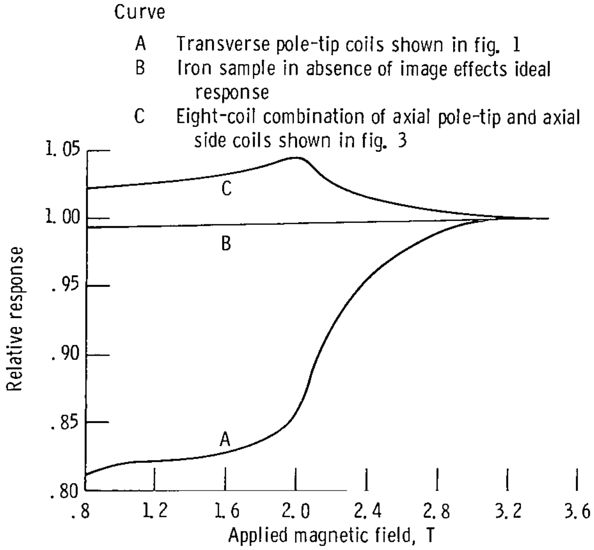

Figure 2. - Response (relative output signal) of vibrating sample magnetometer for two coil geometries for various applied magnetic fields using iron sample.

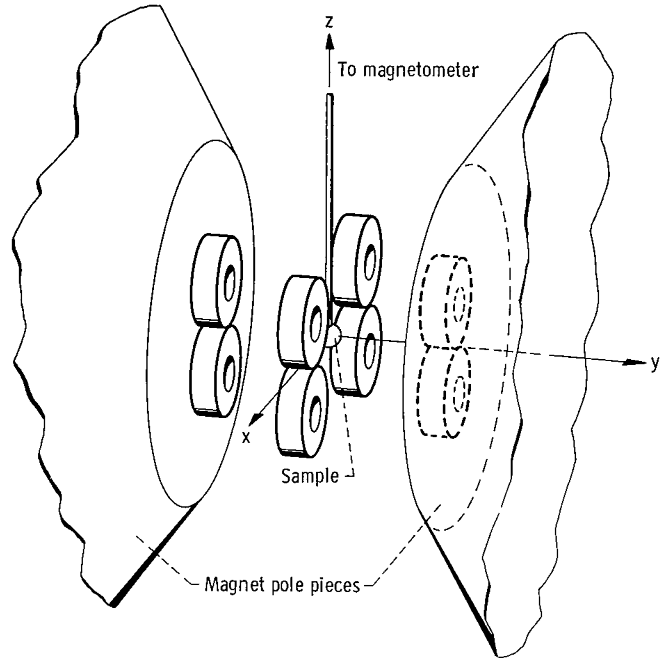

Figure 3. - Placement of final eight-coil combination, four axial pole-tip coils and four axial side coils.

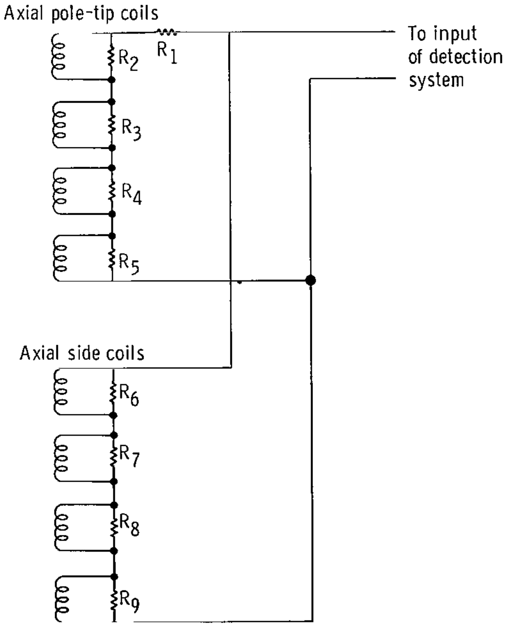

Figure 4. - Schematic wiring diagram for eight-coil combination. Resistors R_2 to R_9 are large value resistors which balance individual coils of each set. Resistor R_1 is used to produce a balance between axial pole-tip coils and axial side coils.

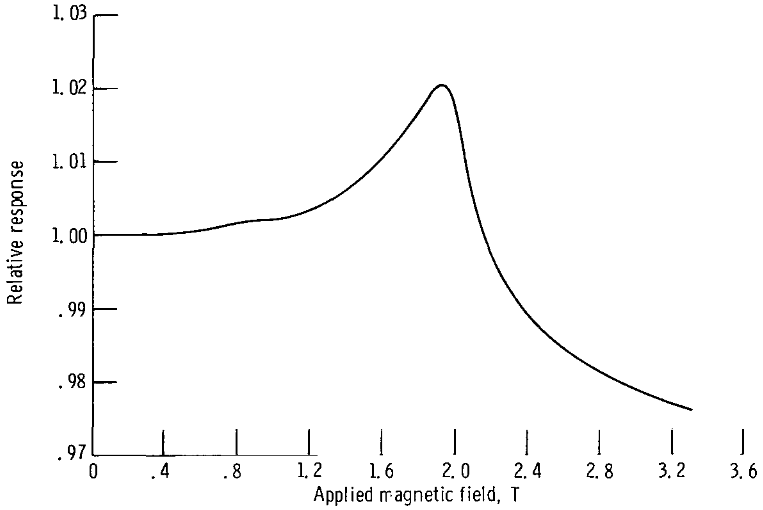

Figure 5. - Response (relative output signal) of vibrating magnetometer for eight-coil combination. For fields below 1.2 teslas data were obtained by using magnetic moment of small coil cemented to sample rod. Above 1.2 teslas iron sample was used corrected for its high field susceptibility.

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