A Home-built Vibrating Sample Magnetometer

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ABSTRACT

This work presents the design and construction details of a computerized and fully automated vibrating sample magnetometer (VSM), one of the most commonly used instruments for measuring magnetic properties of materials.

In this design, the sample to be analyzed is placed in a homogeneous magnetic field produced by an electromagnet which magnetizes the sample and vibrates it vertically between two pairs of pick-up coils. The vibrating sample could then be approximated to an oscillating point dipole and an electromotive force (emf) proportional to the magnetic moment of the sample is induced in the pick-up coils. The induced emf is amplified with a gain of 1000 and is converted into a digital signal by using an in-built analogue to digital converter module of a microcontroller. The magnetization field is varied by varying the supply voltage to the electromagnet and a microcontroller-operated power supply is used for this purpose. The voltage supplied to the electromagnet is also measured after digitization and RS232 standard serial data transmission technique is used to transmit the digitized data obtained from the microcontroller to the serial port of the computer.

Computer software has been developed to receive data from the microcontroller and to plot the hysteresis (Magnetic induction field *B* verses magnetization field *H*) curve. Computer software was developed using Delphi 7 programming language. This software is capable of calculating some useful parameters related to the *B*-*H* curve. The VSM constructed in this work has been used successfully to obtain the *B*-*H* curve of an iron sample for preliminary testing and has proven its capability of producing *B*-*H* curves of other ferromagnetic samples.

1. Introduction

With the technological revolution, magnets came to limelight showing greater potential especially in the mechanical field. With the heavy use of magnets in a large spectrum of industries, research into the properties of magnetism emerged and different magnetometers were developed to measure and characterize magnetic materials. Several methods have been used for the measurement of magnetic properties and they can be divided into two major categories [1] the force technique and inductive technique.

The two main instruments which are based on the force technique are the ‘Faraday balance’ and ‘alternating gradient force magnetometer’ (AGM). The Faraday balance[2] detects a magnetic moment of a sample by measuring the force on the sample in an inhomogeneous magnetic field. The force is measured with an analytical balance at which the sample is suspended. In an AGM, the sample is mounted on a piezoelectric transducer which oscillates when the sample is subjected to an alternating magnetic field gradient superimposed on the DC field of an electromagnet.

In the inductive technique, the voltage induced by a changing flux is measured. The most prevalent examples of magnetometers employing this technique are the ‘Hysteresis Meter’ and ‘Vibrating Sample Magnetometer’. The Hysteresis meter usually employs a solenoid or a pair of Helmholtz coils driven by an AC field (typically 50 or 60 Hz). This meter can only be used with relatively low coercivity (magnetic field intensity needed to nullify the already induced magnetic field of a sample) samples. The Vibrating Sample Magnetometer (VSM) is based upon Faraday's law, according to which an e.m.f. is induced in a conductor by a time-varying magnetic flux. In VSM, a sample magnetized by a homogenous magnetic field is vibrated sinusoidally at a small fixed amplitude with respect to stationary pick-up coils. The resulting field change at a point inside the detection coils induces a voltage and this voltage is proportional to the induced magnetic moment of the sample. The first VSM was designed and constructed in 1959 by Professor Simon Forner of the Massachusetts Institute of Technology, USA [3]. Since then, vastly improved versions of VSMs have been developed by various manufactures and are available commercially. However, their extremely high price makes it almost impossible for local researchers to employ them for their magnetic measurements. As a solution to this problem, a VSM was constructed in 1993 at the Department of Physics, University of Colombo [4] by using components available in the local market. The main drawback of this instrument was its manually operation. Therefore, in the work presented in this paper, much attention was paid to make further improvements to develop this design into a computer controlled VSM.

2. Materials And Methods

2.1. Mechanical Apparatus

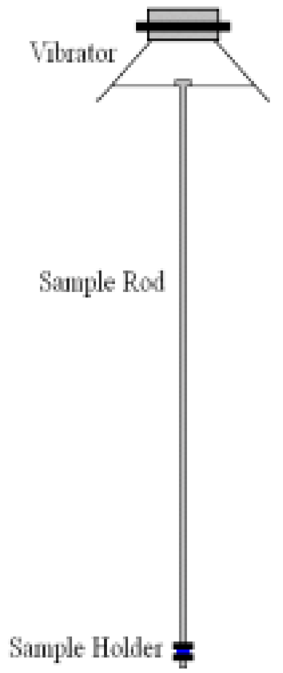

Figure 2.1(a) : Vibrator

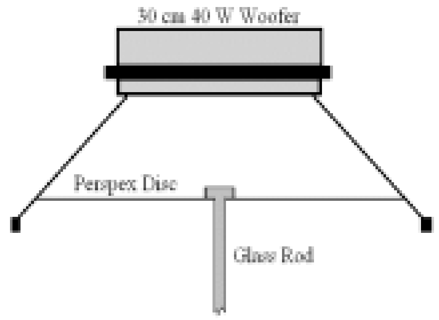

Figure 2.1(b) :Vibrator mechanism

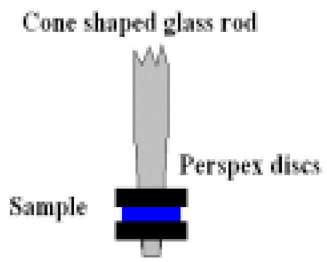

Figure 2.1(c) : Sample Holder

A schematic diagram of the mechanical vibrator of the VSM is shown in Figure 2.1(a). As the vibrator, a 15 cm, 40 W woofer with tightly glued perspex disc, powered by a midrange oscillator (Model E-1205, NF Electronic Instruments) has been used. A sinusoidal signal of frequency 250 Hz is selected to drive the woofer shown in Figure 2.1(b). The sample is mounted at the lower end of the glass rod which is attached vertically to the mechanical vibrator. This rod is called the 'sample rod' and it is 72 cm in length and 3 mm in diameter. The sample to be analyzed is attached to the lower end of the sample rod using a sample holder. The schematic diagram of the sample holder is shown in the Figure 2.1(c). This mechanical vibrator was capable of vibrating the sample with a fixed frequency and amplitude.

2.2 Electro Magnet And Electronic Circuitries

The sample whose magnetic properties to be measured is mounted in the sample holder which vibrates in a homogenous magnetic field. A Laboratory electromagnet (Model P MK II, New Port Instruments, UK) with 10 cm pole diameter and 6 cm pole gap is used to produce the magnetizing field and up to 0.4 T magnetization field can be obtained from this electromagnet by drawing a current of 5 A at a voltage of 40 V (200 W). The magnetic field intensity is varied by varying the current drawn through the coils of the electromagnet and this is done by changing the supply voltage.

2.2.1 Micro-controller Operated Variable Power Supply

A custom-made power supply with a multi-tapped transformer is used to power this electro magnet. Since such transformers are not readily available, one was designed and constructed especially for this purpose by using components purchased from the local market. This multi-tapped transformer has six taps with 1 V, 2 V, 4 V, 8 V, 16 V and 32 V outputs. A maximum 6 A current can be drawn through this transformer at an input voltage of 230 V. The outputs of the transformer are connected to six relays (Model JZC-20F 4088) and by switching them between the selected taps, the necessary outputs are connected serially to produce a desired voltage across the electromagnet. These relays are powered through a C828 and D400 transistor Darlington couple. The base of the C828 transistor is connected through a resistor to a data line coming from the

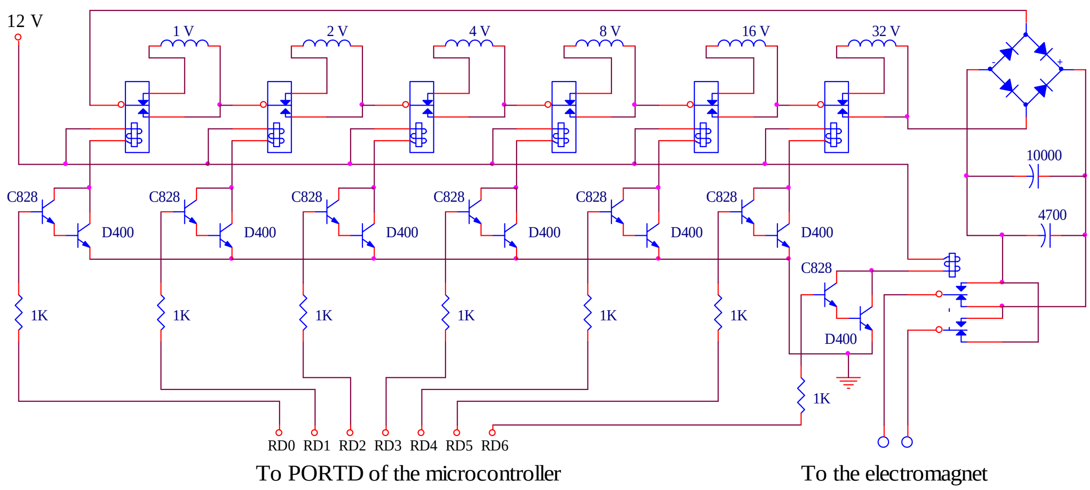

Figure 2.2: Voltage controller circuit

microcontroller. When a voltage of 5 V is supplied to the base of C828, the Darlington couple achieves the saturation mode whereby the relays are switched on. By applying 0 V to the base of C828, the Darlington couple can be brought to its cut-off mode whereby the relays are switched off. The output taps can be connected serially as needed by sending 0 V or 5 V through the data line from the microcontroller. A relay-driven output is connected to a 30 A rectifier bridge for full-wave rectification. The full-wave rectified output is then connected parallely to a capacitor system of 14700 μF for smoothing. The rectified output is connected to the electromagnet by using two flexible wires. The circuit diagram of the Driver circuit is shown in Figure 2.2.

The sample holder is placed at the center of the four pick-up coils mounted on the face of each electromagnet pole. The dimensions of the sample have to be smaller than that of the pick-up coil system so that the sample could be considered as an oscillating point dipole. As a result of the oscillating dipole, an oscillating magnetic field is produced relative to the pick-up coils. According to the Faraday's law, a time varying electromotive force (e.m.f) proportional to the magnetic moment of the sample is induced in pick-up coils due to the time varying magnetic field.

2.2.2 Pick-up Coil Assembly

The VSM in concern uses the system of four pick-up coils to detect the emf induced by the vibrating sample. The assembly of four detection coils is shown in Figure 2.3.

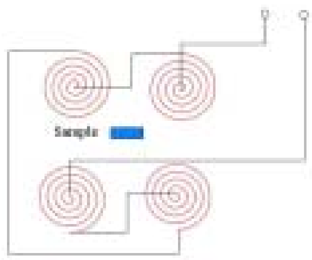

Figure 2.3: Pick-up Coil Assembly

The both upper two coils and lower two coils are connected in series and then the upper pair and the lower pair of coils again are connected in series opposition with each other, as shown in Figure 3.3. By convention, this coil configuration is referred to as the 'transverse coil geometry'.

The magnetic flux lines of the oscillating magnetic dipole will thread the coils and thereby induce an emf in them which is proportional to its magnetization. At any given instant, the oscillating sample is receding from one pair of coils while approaching the other pair. Since the upper and lower coil pairs are wound in series opposition, the resulting induced emfs in the coils add up giving an enhanced signal. Any small variation in the applied field or any horizontal vibration of a sample does not affect the signal because such variations will be in opposite directions in the sample pick-up coils and consequently will get canceled out.

2.2.3. Signal Amplification And Rectification

The signal produced by the pick-up coil system is amplified by an amplifier with high voltage gain and high input impedance. The amplifier is placed away from the electromagnet to reduce the effect of the noises produced by the electromagnet. Noises were screened by installing the amplifier circuitry in an aluminum box, placed away from the electromagnet and using stereo screened wire as a transmission line between the pick-up coil system and amplifier. Two 9 V batteries are used as the power supply of the amplifier to avoid the 50 Hz noise. To eliminate the high frequency noise components, a 22 pF capacitor is connected in parallel to the output of the pick-up coil system at the beginning of the transmission line.

A precision diode circuit is used to rectify the signal. This circuit is used because it does not produce a voltage drop when the signal is rectified. The rectified signal is passed to an analogue to digital (A/D) converter in Channel 1 of a microcontroller for digitization. The digitized data obtained from the A/D converter is proportional to the magnetic moment of a vibrating sample. In order to plot the hysteresis curve, the magnetization field needs to be measured. The magnetization field produced by an electromagnet is proportional to the current drawn through the electromagnet. According to the Ohm's law, the current flowing through the electromagnet's coil is proportional to the voltage supplied to the electromagnet. Therefore, the magnetization field can be determined by measuring the supply voltage and it can have values in the range 0 – 40 V. Since the maximum measurable voltage by the A/D module in the microcontroller is selected as 5 V, the supply voltage of the electromagnet has to be attenuated by a factor of 1/8. This is achieved by using an ordinary inverting amplifier with attenuation of 0.125. The output is sent to an A/D converter in Channel 2 of the microcontroller. The digitized value is proportional to the strength of the magnetization field which is applied by the electromagnet.

In plotting the hysteresis curve, the external applied magnetic field to the sample needs to be varied between a negative value and a positive value. The plotting of the curve can be divided into five steps based on the direction of the magnetic field and its strength.

1. Increase the magnetic field from zero up to the maximum level (the direction of the field is taken as positive).
2. Decrease the magnetic field from the maximum down to zero.
3. Invert the direction of the magnetic field and decrease from zero to the minimum (the direction of the applied field should be negative).
4. Increase the magnetic field from the minimum back to zero.
5. Invert the direction of the magnetic field and increase up to the maximum level (the direction is made positive).

While following these steps, the applied field and the induced magnetic field of the sample have to be monitored. This is done by means of a microcontroller (PIC 16F877A).

As stated earlier, the supply voltage of the electromagnet is controlled by a digital signal. Six terminals from the port D in the microcontroller are connected to the voltage controller circuit. Five of them are switch relays which control the output voltage (pins RD0 to RD4) and the sixth one (RD5) controls the polarity of the output voltage. Then by changing the output values of port D, the magnetic field is controlled as required in the above five steps. Software has been developed to control the value in the port D.

While changing the external magnetic field, the microcontroller reads

1. the induced magnetic moment of the sample, and
2. the strength of the magnetic field with its polarity,

which are fed to A/D Channel 1 and Channel 2 of the microcontroller respectively. After getting each reading from the microcontroller-based system, data is sent to the computer for further calculations and to plot the hysteresis loop. This VSM uses RS232 serial data protocol to transmit data from the microcontroller to the computer.

3. SOFTWARE

The microcontroller is programmed by using PICC compiler and uses MPLab editor. The computer uses a program written in Delphi 7 to communicate data, to plot the hysteresis loop and to do the necessary calculations. The software in the computer runs parallel to the software at the microcontroller.

The prime task of the microcontroller is to read the applied magnetization field and induced magnetic moment of the sample, while varying the applied magnetization field, and sending these information to the computer. The prime tasks of the computer are to receive data from the microcontroller, to plot a graph, and to do further calculations. In addition to plotting a hysteresis loop, area within the hysteresis loop, coersivity of the sample and retentivity (stored magnetic field) of the sample are calculated by the computer software.

4. RESULTS

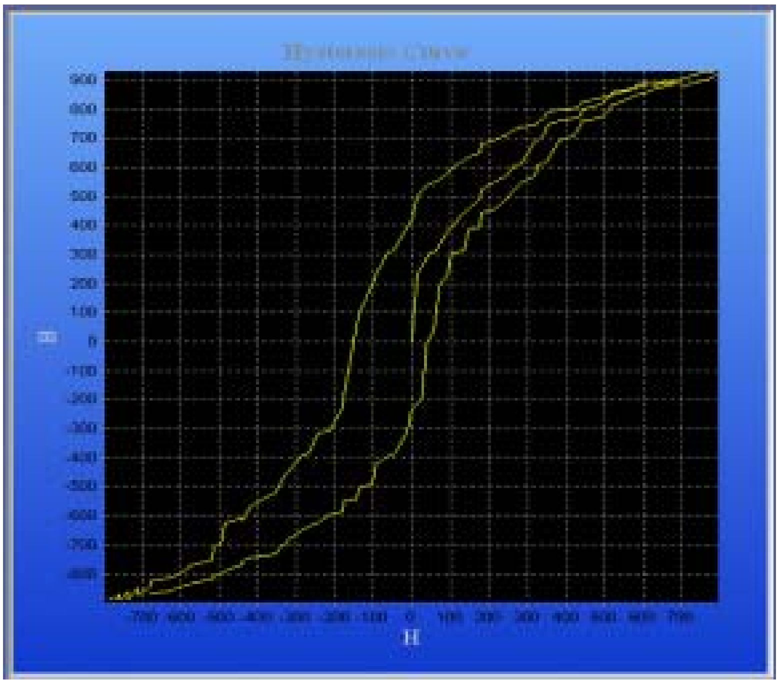

Figure 4.1: Hysteresis loop obtained for an Iron sample

5. DISCUSSION AND CONCLUSION

Fully automated and computerized vibrating sample magnetometer was constructed at the Department of Physics, University of Colombo using locally available components. To the best of our knowledge this VSM could be the first Vibrating Sample Magnetometer which has been designed and constructed in Sri Lanka. This VSM is capable of producing hysteresis loops which are similar in basic shape of hysteresis loops obtained from other sophisticated, expensive and advanced magnetometers[5].

Hysteresis loops of an iron and nickel samples were obtained successfully using the constructed VSM. The whole process of measurements made on a sample including the sample mounting takes less than 45 minuets. The hysteresis loop obtained for an iron sample is shown in Figure 4.1. The basic features of this hysteresis loop are not much different from what is expected.

The maximum strength of the magnetization field produced by the electromagnet of this VSM was not enough to reach the saturation level of the magnetization of the sample. An electromagnet which produces a higher magnetization should be used to overcome this problem. VSMs which use electromagnets having magnetization fields up to 1.7 T [6] have been reported. However, there could still be limitations to the highest magnetic field produced by an electromagnet. This drawback not only affects the saturation level but also has an impact on the other measurements which are obtained from the hysteresis curve.

The hysteresis curve plotted was not a smooth one and it was due to the low resolution of the power supply of the electromagnet. By minimizing the step size of the output voltage levels of the supply it may be possible to overcome this problem. In order to achieve this, some extra transformer taps with low voltage levels must be inserted into the transformer. The minimization of step size can also be achieved by using another voltage supply which could operate smoothly by an external digital signal.

The voltage produced in pick-up coils was related to the amplitude and frequency of vibrations of the vibrating sample. Then, by using a sample vibrator with high amplitude and high frequency, it should be possible to produce a higher e.m.f in the pickup coils. Hence the amplitude of the signal can be made large relative to noise.

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