Modification of a Princeton Applied Research FM-1 vibrating sample magnetometer

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A Princeton Applied Research model FM-1 vibrating sample magnetometer (VSM) has been modified using lock-in detection, automatic data acquisition, and microcomputer control. The practical sensitivity in the updated version has been improved to 10^{-4} emu. Data collection and data management are quicker and greatly simplified. Through menu driven software and modular design, the overall ease of use has been enhanced. The original layout of the FM-1 has been retained so that no versatility is lost for either the original or modified version.

I. INTRODUCTION

The vibrating sample magnetometer (VSM), first developed by Foner,[1] is a basic research tool that has been used since the late 1950s to investigate the magnetic properties of materials. The instrument has been used in several configurations, some fabricated "in-house" by various laboratories and others developed by commercial instrumentation organizations. One of the most widely used configurations is the original commercial model FM-1 unit marketed in the 1960s by Princeton Applied Research (PAR) Corporation. This unit utilized Foner's basic design principles and implemented the "servoloop" concept of Foner to obtain null measurements of the magnetic moment.

An upgraded version of the original design, the model 155, was marketed by Princeton Applied Research in 1964. In recent years, several other commerical VSM instruments have become available. Many of the newer commercial VSM systems include data acquisition and computer interface options. There have also been numerous noncommercial VSM innovations.[2,3] Reference 3 describes a digital approach in which the lock-in detection of the low level VSM signal is accomplished in software.

The purpose of this short article is to describe the manner in which an early model FM-1 system has been "modernized" by the use of lock-in detection techniques, automatic data acquisition, and computer control instrumentation. Upgrades of this type may be of interest to the scientific community for three reasons: (1) the high cost of purchasing completely new units, (2) the availability of older VSM vibration heads (such as the FM-1 head) of sound design, and (3) the growing availability of data acquisition and computer equipment at modest cost. The information provided by this report may prove useful to investigators who wish to upgrade their own FM-1 or other early model VSM magnetometer systems.

The central component for the new system is the vibration head unit of the FM-1 system. This unit is of sound design and has the research advantage of a top loaded sample rod assembly. Some of the newer commercial units have a permanently mounted sample rod that may be swung out of the magnet gap for sample access. Such a design, while convenient for routine work, is not convenient when helium cryostats or high temperature furnaces are needed. The FM-1 head also has an isolation ballast system to minimize the level of mechanical vibration outside the head unit. Of course, almost any VSM vibration head could be used for the system modifications described in the following sections.

For convenience, the drive electronics from the original FM-1 were used to drive the VSM head, although in principle any reasonably stable oscillator and low frequency amplifier of moderate power could be used for this purpose. The remainder of the electronic instrumentation was relatively modern, including a commercial superheterodyne lock-in amplifier for sample signal detection, an ac digital voltmeter for reference signal level measurement, a Hall effect gaussmeter for magnetic field measurement, a data acquisition system to collect readings from the lock-in amplifier, and a personal computer to manage the entire system. The design philosophy was to introduce modifications which would allow the FM-1 system to be operated in its original configuration if desired. The head modification in Sec. I was made with this philosophy in mind.

The article is divided into four specific sections concerned with (1) general considerations and head modifications; (2) VSM system instrumentation; (3) software; and (4) the VSM data acquisition station.

II. GENERAL VSM CONSIDERATIONS AND FM-1 HEAD MODIFICATIONS

As in the original PAR design, the FM-1 vibration head unit is used to drive the sample rod at 82 Hz to vibrate the sample under test and produce the sample signal. Some modifications were required, however, to obtain a strong reference signal for use in the computer data analysis. In the original PAR design, a vibrating capacitor is used with a feedback controlled high voltage source (0–100 V dc) to obtain a reference signal. This signal is then mixed with a similar signal from the sample pickup coils but 180° out-of-phase to produce an input ac signal for the null measurement servoloop. The ac signal is fed into a

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lock-in amplifier and the dc voltage output of the lock-in amplifier is suitably amplified and applied to the capacitor. As a result of this feedback arrangement, the capacitor voltage stabilizes at whatever value is necessary to yield a null ac signal condition after the mixer. The output reading from the FM-1 is simply the capacitor voltage. This voltage is directly proportional to the magnetic moment of the sample under test. Because the detection scheme is based on a null condition between the sample and reference signals, the output voltage value is independent of changes in the vibration amplitude.

Most of the current approaches avoid the complications of such an ac null technique by simply using state-of-the-art lock-in detection instrumentation to analyze the sample coil signal by itself. The effects of changes in vibration amplitude on that sample signal are either minimized, by using a constant amplitude drive of one form or another, or ignored. For situations for which the samples are more or less the same it is sufficient to use a stable drive signal. For conditions where a wide variety of samples may be encountered, more elaborate drive schemes which use mechanical cams or modified Mossbauer transducers are needed.

For the present purposes, it was desired to have a reference signal which was of high amplitude and proportional to the drive amplitude, similar to the original Foner system.[1] This was accomplished by fitting a small pickup coil assembly on the base of the head unit and attaching a small permanent magnet to the vibration rod assembly just below the existing capacitor plate. It was not necessary to remove or modify the vibrating capacitor assembly in the FM-1 head in any way. The essential features of this arrangement are shown schematically in Fig. 1. The permanent magnet was a rubber ceramic composite magnet, cut into a ring shape and bonded to a brass nut with epoxy cement. The nut was then attached to the existing threaded rod support structure for the vibrating capacitor plates. The pickup coil assembly consisted of two counterwound 400 turn coils. The coils were wound onto an epoxy-glass composite core that was mounted in the FM-1 head using pre-existing screws. The ac peak-to-peak voltage output under prescribed FM-1 set up conditions (drive amplitude of about 0.25 mm) is about 10 mV. This signal output is used to provide a measure of the vibration amplitude for normalization purposes. The software uses both the sample pickup signal level and the reference level to obtain the sample moment. System and software details are provided in subsequent sections.

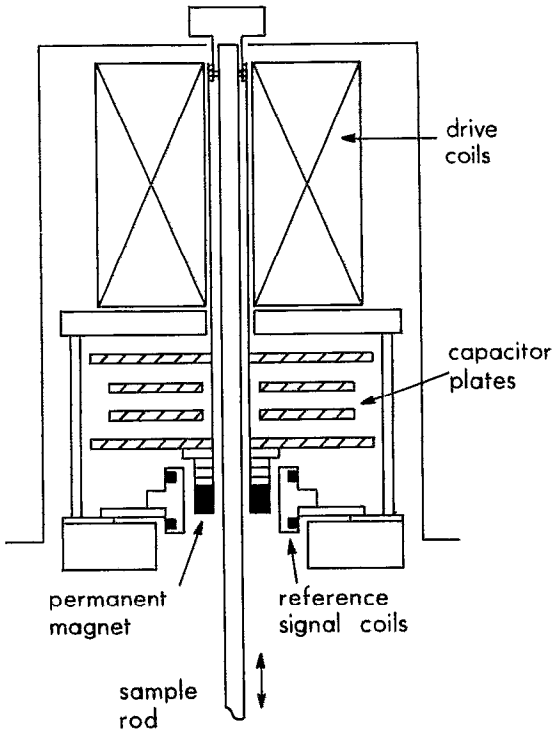

FIG. 1. Diagram of the Princeton Applied Research FM-1 vibrating sample magnetometer drive head with the added permanent magnet and normalizing signal coils.

III. VSM SYSTEM INSTRUMENTATION

The overall VSM system is shown schematically in Fig. 2. The existing FM-1 VSM console is used to drive the VSM head and provide a reference signal for the Ithaco Dynatrac 3 lock-in amplifier. The reference signal from the pickup coil assembly in the modified head unit is measured by a Keithley Model 177 ac digital voltmeter (DVM). The usual sample signal from the pickup coil assembly in the magnet gap serves as the low level input for the lock-in amplifier. A conventional Hall effect gaussmeter is used to monitor the magnetic field in the magnet gap.

The sample signal from the lock-in amplifier, the reference signal from the digital voltmeter, and the magnetic field signal from the gaussmeter are monitored by the data acquisition unit (DAU), Hewlett-Packard model 3497A; the DAU contains a dc digital voltmeter, a 20 channel multiplexer, a two channel programmable voltage source, and a fixed value current source. The programmable voltage source is used in conjunction with the Gaussmeter signal to control the magnet power supply. The constant current source is used with the GaAs temperature sensor in the sample rod (dotted line). The diode voltage, monitored by the DAU and calibrated in software, determines the sample temperature. For high temperature applications, a thermocouple is used for temperature measurement.

The DAU is controlled by a Hewlett Packard Model 86B microcomputer. The software described in the next section causes the DAU to measure the various voltage inputs in an appropriate sequence and then uses these inputs to compute magnetic moment, field, temperature, etc., and also steps the dc field according to various menu selected options.

The above system is similar, in a generic sense, to the various commercial computer controlled systems available on the market. The point to be emphasized here, however, is that one may put together such a VSM system (1) from any available head unit and off-the-shelf electronics components, and (2) at a cost which is significantly below that

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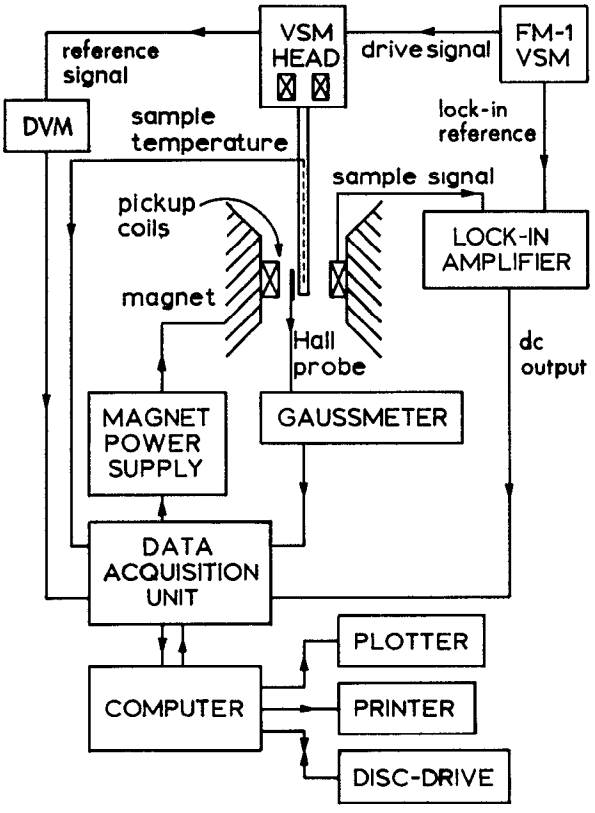

FIG. 2. Block diagram of the modified vibrating sample magnetometer system.

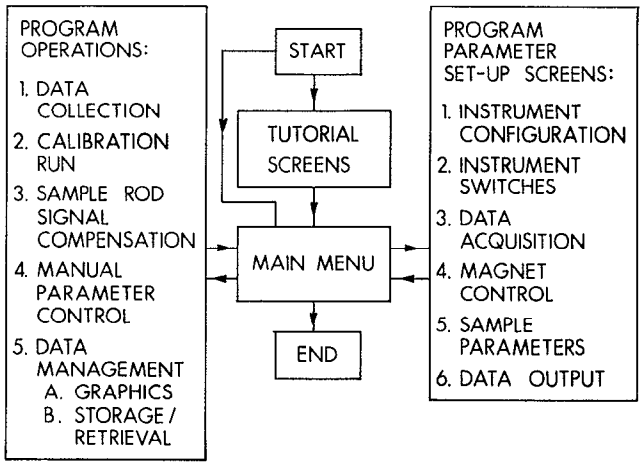

FIG. 3. Block diagram of the vibrating sample magnetometer system software.

of a packaged commercial system. Since the unit is not a "black box," it is more amenable to modification to specific user requirements.

IV. SOFTWARE

The software was written in the HP BASIC language for the Hewlett-Packard Model 86B computer and compatible systems. It was designed to offer options in a menu format with default values for rapid setups under "typical" run conditions. A block diagram of the program features is shown in Fig. 3.

Different options are available at various stages of program operation. At program start, for example, the beginning operator may select a series of tutorial screens. The experienced operator may skip these tutorials and move directly to the "main menu" selection options.

There are a series of "program parameter setup screens" to allow the operator to specify or reconfigure the various instruments, change instrument switch settings, initialize data acquisition parameters, set up magnet and field control, input sample parameters, and select mode(s) for data output. Each of the screens has preset default options for a selected "standard" mode of operation. Under "magnet control," for example, this may include a particular magnet calibration and a particular stepping sequence of control voltages for the magnet power supply to cycle the electromagnet through a particular field range . If it is necessary, however, to change power supplies, magnets, or field steps, the magnet calibration and power supply response parameters can be revised as needed for the measurement task at hand.

On the subject of field control, the approach here has been to avoid active field control through software. It is simply too slow to have the system read the field and step the magnet current according to some sequence designed to allow the field to arrive at a preset value, make a magnetization measurement, and then step the field to the next preset value. While algorithms exist to do this, it has been found to be more expedient to specify the desired sequence of field values, use a magnet calibration curve of field versus current to convert the field steps to current steps, and have the computer/DAU send appropriate voltages to the magnet power supply to step the current. The actual field value at each current step is read during measurement. This approach yields holding values in field that are not quite the same as in the starting sequence, but the small differences make little difference when obtaining hysteresis loop data, curves of moment versus field, etc. Under conditions where an exact field value is desired a manual parameter option control is available.

Under "program operations" there are several options that need specific comment. First, it is necessary to use some sort of standard sample for calibration purposes from time to time. The "calibration run" option leads the operator through a series of steps to accomplish such a calibration. These steps include mounting and centering of the calibration sample, setting the field at some level required to saturate the standard sample, having the DAU record the system response from the standard sample, and entering the moment value for the standard. The "sample rod signal compensation" allows one to enter a background diamagnetic response in emu/Oe which is to be subtracted from the actual moment measurement. This allows the operator to determine ferromagnetic moments versus field against strong background signals due to a paramagnetic

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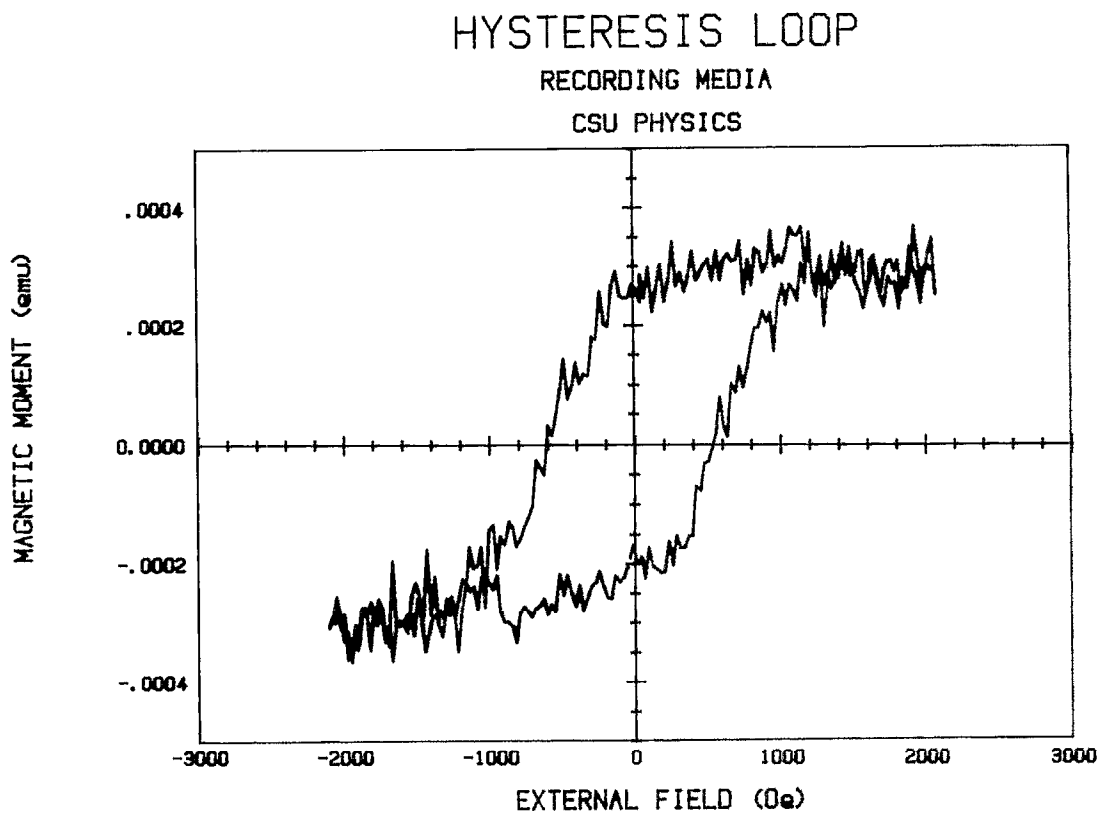

FIG. 4. Low level hysteresis loop of magnetic moment vs magnetic field obtained with the modified vibrating sample magnetometer system.

substrate, sample holder, sample rod, or other materials. Such an option is particularly useful for very low moment thin films. A "manual parameter control" option allows the operator to use the system in the old manual mode of point-by-point measurements. The operator can manually set the field, temperature, sample position, or other parameters, execute a measurement, and proceed to the next data point.

The above discussion of the system software is necessarily abbreviated. Additional details may be obtained directly from the authors.

V. VSM DATA ACQUISITION STATION

To facilitate portability and convenient setup for other applications, the microcomputer, data acquisition unit, printer, plotter, lock-in amplifier, and digital voltmeter are all installed in a portable cabinet. The DAU, lock-in amplifier, and digital voltmeter are rack-mounted, while both printer and plotter are placed on retractable shelves within the cabinet.

Most of the system is hard wired and no shifting of equipment is necessary for other uses. In order to avoid confusing wiring switchovers a patch panel was constructed, with BNC connectors for each of the multiplexer channels of the DAU. Also included in the patch panel are BNC connectors for the voltage output and control functions of the dual channel programmable voltage sources in the DAU. The minimum output increment of the programmable voltage source is 2.5 mV. To achieve finer control of the magnet power supply, a voltage divider was included in the patch panel. The voltage output can be divided by one, ten, or one hundred by use of a selector switch mounted on the panel.

No part of the data acquisition station is hard wired to the existing VSM system. The entire console may be conveniently moved from experiment to experiment. In addition, each component within the station may be used individually. There is therefore no loss of utility for the individual equipment items or for the overall system.

Before the modification of the FM-1 magnetometer was done, measurements below 0.1 emu were difficult and time consuming. With the upgraded system, measurements can be made routinely down to a level of 1×10^{-4} emu. Figure 4 shows a graph of a typical hysteresis loop measurement at this level, which was obtained directly from the microcomputer. Such results can now be obtained in 10–20 min, compared to several hours of tedious measurements, data reduction, and plotting required with the original magnetometer unit. Measurements performed on larger emu samples can usually be done in 10 min or less. No serious effort has been made to obtain higher sensitivity. Careful attention to pickup coil design, vibration prob-

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lems, etc., could easily improve the sensitivity by one or two orders of magnitude.

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