AN AUTOMATIC CONTROL AND DATA LOGGING SYSTEM FOR THE DETERMINATION OF MAGNETIC PROPERTIES OF MATERIALS FOR NONDESTRUCTIVE EVALUATION

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INTRODUCTION

In recent years there has been considerable progress in the area of microprocessor controlled automated test systems for the measurement of magnetic properties of materials [1,2]. Lately commercial systems have become available [3,4]. This has been made possible by the rapid growth of the microcomputer industry in the last eight years so that independent, or personal, computers have become available with enough capability and at sufficiently low cost to make on line control and data logging of even quite small experimental systems both economical and desirable.

The production of reliable bulk magnetization measurements has until recently been a problem, since exact manual demagnetization of specimens prior to taking data is a very time consuming operation. Specimens for which the hysteresis curves should be symmetric about the origin have often been shown displaced and in most cases this is due to inadequate demagnetization. Similar problems have arisen with anhysteretic magnetization and in that case the problem is even worse since a number of a.c. demagnetizations have to be made at different d.c. field offsets.

The purpose of this paper is to describe a magnetic testing system which has been designed and built at the Ames Laboratory in the last year. This system enables the bulk magnetic properties of ferromagnetic materials to be measured rapidly and accurately under both stressed and unstressed conditions without problems of demagnetizing effects in the samples.

ADVANTAGES OF FIELD CONTROL

Magnetic properties such as the initial susceptibilities of both the anhysteretic and the normal magnetization curves can only be measured after a correct demagnetization. The coercivity and remanence are easier to measure after demagnetization.

With microcomputer control of the magnetic field H it is of course a fairly simple matter to devise algorithms for demagnetization and anhysteretic magnetization or indeed for any magnetization process which may be of use. These algorithms can be tested and refined to give a high degree of reliability. The magnetic data obtained in this way can then be superior to that obtained previously and can be produced much more rapidly.
Algorithms for both demagnetization and anhysteretic magnetization have been given in a previous paper [2], and while these continue to be refined they remain basically the same as was reported earlier. In most cases, but not all, the correctness of the demagnetization algorithm can be checked from the symmetry of the subsequent magnetization curves. The reliability of the anhysteretic algorithm can be checked by observing coincidence of anhysteretic data points when the d.c. field component is increasing and when it is decreasing. If these points do not coincide then the curve cannot be hysteresis-free.

IMPLEMENTATION

The present system which was designed and built at the Ames Laboratory is shown in schematic form in Fig. 1. An IBM PC, 16-bit personal computer with 128K user RAM, dual disk drive and monochrome monitor was chosen as the controller. The main advantage of this machine over earlier 8-bit microcomputers lies in its speed of operation and also in the amount of hardware and software now available for it. For the present requirements it was not found necessary to go beyond the capabilities of the basic IBM PC although more advanced versions are available for more sophisticated applications.

Control of instruments and acquisition of data was achieved by incorporating a Tecmar Labmaster [5] into the system. This unit has two independent digital to analog converters with 12-bit resolution which allow two devices to be controlled directly from the computer. The D/A

Fig. 1. Block diagram of the Automatic Control and Data Logging System.
output channels have a 5 μs settling time and selectable output ranges of ± 2.5 V, ± 5 V, ± 10 V, 0–5 V and 0–10 V. On the ± 10 V range the resolution is 5 mV. The Labmaster also has eight analog to digital converters with 12-bit resolution and selectable input ranges of ± 10 V or 0–10 V. These allow readings to be taken from up to eight measuring instruments, although in practice only three of these have so far been used to read magnetic field H, flux density B and magnetostriction λ. An optional programmable gain which enables greater resolution to be attained over small voltage ranges was found to be highly desirable. This enables the A/D to read voltages of full scale deflection ± 20 mV with 12-bit (i.e. 4096 steps) resolution corresponding to an ultimate resolution of 10 μV.

It was found that more than two control lines were desirable so in addition to the Labmaster the system has a Kepco [6] SN-121 Digital Programmer which also acts as a D/A converter. This device uses the IEEE 488 bus and so the IBM PC was equipped with a Tecmar IEEE-488/HPIB bus controller card to communicate between the computer and the SN-121. One output from the SN-121 was used to control the magnetic field by using it as the input to a Kepco BOP 72-5M programmable bipolar power supply, which acts as a power amplifier. The other output line was used along with the output lines from the Labmaster for control of existing instruments, such as the zero reset on the integrating voltmeter/fluxmeter, and various functions of the chart recorder.

The magnetic field H was measured with a custom designed Hall probe with an active area of 1 mm² available from F. W. Bell [7] as a modification of their standard BH-207 Hall probe. The probe was located on the surface of the specimen where the tangential field was detected. The Hall voltage was measured using a Walker MG-3A Gaussmeter [8], the output of which was connected to both the chart recorder and one of the A/D input channels of the Labmaster.

The magnetization M, or flux density B, was measured using a Walker MF-3A integrating voltmeter/fluxmeter which was connected to a search coil on the specimen. The output from the fluxmeter was connected to the chart recorder and another of the A/D input channels of the Labmaster.

MEASUREMENTS

One of the most serious problems encountered in making meaningful measurements of the bulk magnetic properties of materials of finite length is the demagnetizing field caused by the induction of magnetic poles near the ends of a ferromagnet when placed in an applied field. As a result of this, even when the H field is measured locally on the surface of the specimen, quite serious errors begin to affect the results at length to diameter ratios below 10:1. Permeability appears to decrease while coercivity appears to increase. These effects are totally artificial and could be corrected for by making demagnetizing field corrections. However, it is more elegant and useful to eliminate them from the measurements so that no correction is necessary. In the present system they have been overcome completely by making modifications to the electromagnet which allow the pole pieces to slide freely and enable them to be placed directly on the ends of the specimen. Tests with several different lengths of the same rod of material showed no differences in the magnetic properties, indicating that the demagnetising effects had been eliminated. A photograph of the system is shown in Fig. 2.
RESULTS

The influence of chemical composition heat treatment and microstructure on the magnetic properties of the iron carbon alloy system has been investigated. A brief summary of the results is included here to illustrate the performance of the system.

For a given heat treatment the hysteresis loss and coercivity increase with carbon content while the anhysteretic and normal susceptibilities at the origin decrease. This is shown in Figs. 3 and 4.

For identical chemical compositions and mechanical treatments the magnetic properties depend strongly on the microstructure as shown in Figs. 5 and 6. These results are for the same specimen given two different heat treatments, the normal air cool from 850°C in Fig. 5 which produces a lamellar pearlite structure, and a very slow cool with thermal cycling in Fig. 6 which spheroidizes the Fe₃C inclusions.

Since the magnetic domain walls are pinned by the Fe₃C inclusions, the amount of pinning and the strength with which the domain walls are pinned depends on the size and distribution of the inclusions as has been discussed by Habermehl et al. [9]. The results of the dependence of various magnetic parameters on composition and microstructure are shown in Figs. 7-11.
Fig. 3. Magnetization curves for a specimen of Fe-C alloy containing 0.006 wt.% C after air cooling from 850°C.

Fig. 4. Magnetization curves for a specimen of Fe-C alloy containing 1.00 wt.% C after air cooling from 850°C.
Fig. 5. Magnetization curves for a specimen of Fe-C alloy containing 0.43 wt.% C after air cooling from 850°C to give lamellar pearlite.

Fig. 6. Magnetization curves for a specimen of Fe-C alloy with 0.43 wt.% C after slow cooling to produce spheroidized Fe₃C inclusions.
Fig. 7. Variation of the coercivity $H_C$ with chemical composition and microstructure. $S =$ spheroidized, $N =$ normalized, $X =$ extruded.

Fig. 8. Variation of the hysteresis loss $W_H$ with chemical composition and microstructure. $S =$ spheroidized, $N =$ normalized, $X =$ extruded.
Fig. 9. Variation of the remanence $M_r$ with chemical composition and microstructure. $S =$ spheroidized, $N =$ normalized, $X =$ extruded.

Fig. 10. Variation of the anhysteretic susceptibility $X'_an$ with chemical composition and microstructure. $S =$ spheroidized, $N =$ normalized, $X =$ extruded.
CONCLUSIONS

In order to obtain meaningful results on the bulk magnetic properties of materials it is necessary to perform certain operations, such as demagnetization, reliably and reproducibly. Other procedures such as the anhysteretic magnetization require a very complex sequence of field variations. A microcomputer control system has been presented which enables exact control algorithms to be devised for these processes. Another feature of the system is its capability for reading and recording data from up to eight instruments at any time. This enables the system to continue changing the magnetic field and recording results without supervision.

Results have been presented showing the effects of carbon content and microstructure on the magnetic properties of the iron-carbon alloy system.

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