Mobile Ferrograph System for Ultrahigh Permeability Alloys

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Abstract:
This paper presents a mobile ferrograph system for measurement of magnetic parameters of ultrahigh permeability alloys. The structure of developed system is described, as well as exemplary measurement results of $Co_{67}Fe_3Cr_3B_{12}Si_{15}$ alloy used in space applications are presented.

Keywords: *ferrograph, hysteresis, amorphous alloys, mobile measurement system*

1. Introduction

Measurement of magnetic parameters of materials is an important issue in various applications, e.g. determining the type of a transformer core or verifying structure integrity of 3-D printed inductive elements. By measuring the full magnetic hysteresis loop, one can obtain results on power loss, permeability, or other parameters of a sample, which are essential when designing switching-mode power supply systems. Hysteresis measurement is usually performed with fluxmeters [1], ferroscopes, ferrographs [2] or hysteresisgraph systems [3].

Additionally, recently there are methods of nondestructive testing (NDT) developed, which allow for stress evaluation in constructional steels on the base of hysteresis curve measurements [4]. Contemporary hysteresisgraph systems are designed for stationary, laboratory operation, and therefore are unsuitable for NDT in steel constructions. The presented solution is a fully mobile, wheeled ferrograph system. Due its relatively light chassis and modular construction it was already used in various investigations [5].

The second problem presented in this paper are the ultrahigh permeability alloys. Modern magnetic materials include ferrites, amorphous alloys, nanocrystalline alloys, Heusler alloys etc [6], [7]. Some of these new materials exhibit very high relative magnetic permeability, in some instances higher than 500 000. Because this value is many orders of magnitude higher than typically encountered in e.g. electrical steels, special approach to measurement of the magnetic hysteresis curve is needed. Thus, we propose modifications which allow such measurements on the ferrograph system originally developed for NDT constructional steel testing.

2. Developed System

The system is used for NDT of materials by the means of change in behavior of magnetization characteristic. It has a modular mechanical and software structure, which allows for easy replacement of each part and ensures high flexibility for various applications. The software has been written in LabVIEW programming environment, in which the modularity is easy to achieve.

2.1. Mobile Ferrograph System

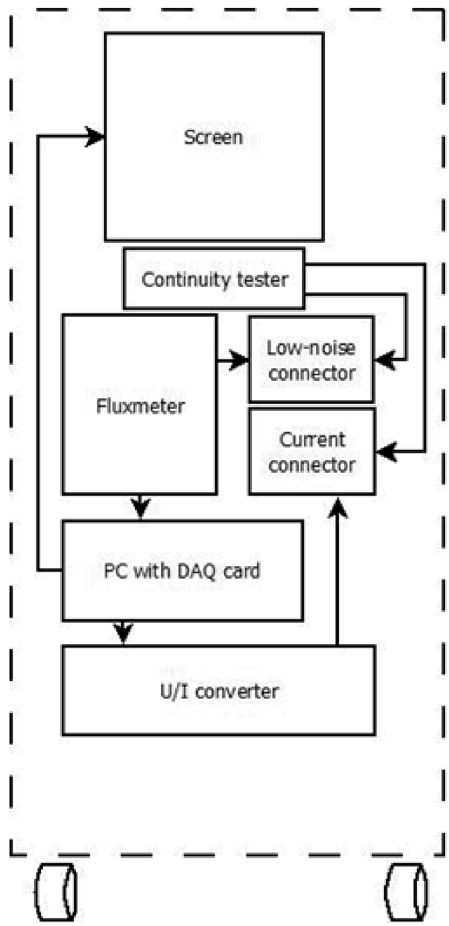

Fig. 1. Schematic diagram of the developed Blacktower Ferrograph System

Figure 1. presents a block diagram of the Blacktower Ferrograph System. The core of the system is a PC equipped with an NI PCI-6221 DAQ card, wh ich is fed signals from a Lakeshore 480 fluxmeter and a KEPCO BOP36-6M U/I converter. The software controls the U/I converter, which passes current to the magnetizing

coils through the current connector (Fig. 1). The voltage from measurement coils is fed to the fluxmeter by low-noise connector. The system is also equipped with a continuity tester, to ensure that there is a separation between input and output connectors, because from experience, often the two are shorted through an unintended insulation breakdown.

The system was designed and constructed as a mobile unit, allowing for additional measurement flexibility.

2.2. Measurement Stand for Ultrahigh Permeability Alloys

The ferrograph system was expanded with new functionality to accommodate for measurements of ultrahigh permeability alloys, such as used in space applications. The permeability of such materials is so high, that even relatively weak Earth's magnetic field (~40 μT) can significantly influence the measurement results (order of ±10%). Thus it was necessary to shield the sample from external field influence. In our approach it is done with three-axial Helmholtz coils (Fig. 2), with proper current power supplies and magnetometer (the latter omitted in schematic for clarity), which cancel out external field influence to the level lower than 0.1 μT.

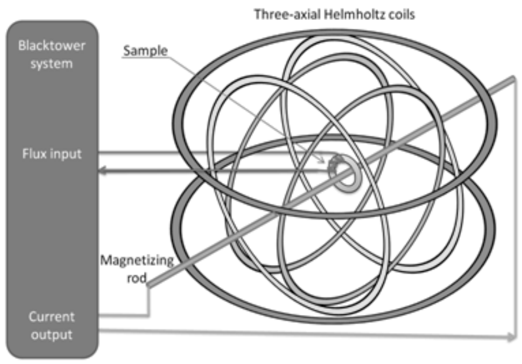

Fig. 2. Schematic diagram of the ultrahigh permeability alloys measurement test stand

Another issue is connected with magnetization of the sample – with so high a permeability, very low magnetizing fields have to be used. For standard magnetizing coils wound on the sample, U/I converter should have very low maximum current output. In our system it would significantly affect its performance, as an additional source of noise and errors. This problem can be solved with usage of straight magnetizing rod instead of magnetizing coils. What is more, for all necessary calculations, the resulting magnetizing field H can be calculated the same as for the magnetizing coil of 1 turn. It also has better field uniformity than magnetizing coils with low windings number.

3. Exemplary Results

The developed system was utilized in measurements of materials used in the construction of fluxgate sensors for space applications. The amorphous alloy $Co_{67}Fe_3Cr_3B_{12}Si_{15}$ is a novel magnetic almost zero magnetostriction and remarkable soft magnetic properties. Magnetic cores made of $Co_{67}Fe_3Cr_3B_{12}Si_{15}$ ribbons have a number of advantages, especially, high initial and maximum magnetic permeability. Moreover, the alloy is characterized by low core loss. Magnetic properties of this alloy can be improved by inducing magnetic anisotropy by the annealing in magnetic field. After such processing, the hysteresis loop changes its shape and becomes square or flat depending on the direction and magnitude of the induced magnetic anisotropy. Therefore, the possibility to measure its shape (Fig. 3) is very important, as it directly influences the fluxgate characteristics.

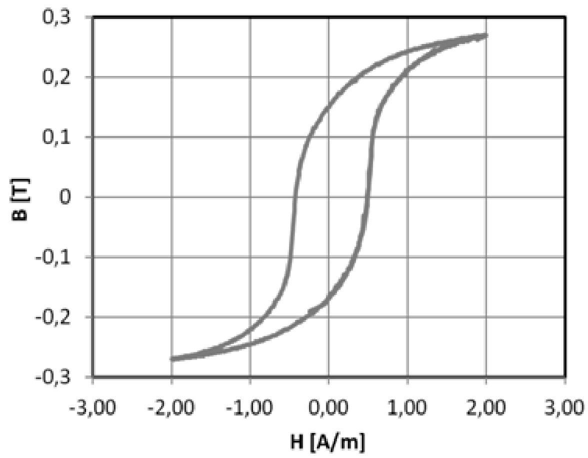

Fig. 3. Exemplary results of the measured quasi-static hysteresis loop of $Co_{67}Fe_3Cr_3B_{12}Si_{15}$ alloy. Note the extraordinarily low coercive force of the material

4. Conclusions

The presented ferrograph system has many novel features, such as modular software and hardware architecture and mobile construction, allowing e.g. for NDT testing of steel elements. Moreover, it was modified for measurements of ultrahigh permeability alloys used for space applications. The shielding Helmholtz coils compensate external fields influence, while the magnetizing rod achieves better field uniformity. The additional advantage is separation of the sample from the current-carrying rod, thus ensuring that no self-heating will influence he measurement results. Calibration and adjustment of the system were carried out with certified standards, allowing for 0.1% accuracy in measurement of flux density B, and 0.01% accuracy in measurement of magnetizing field H.

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