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A Labview based Measuring System for Hysteresis Loops of Magnetic Materials

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***Abstract*—Magnetic materials exhibit varied hysteresis behaviour at different operating conditions. The exact determination of magnetic characteristics requires an accurate measurement setup. A low cost high performance digital hysteresis loop tracer has been built to measure magnetic characteristics of ferromagnetic materials under controlled sinusoidal and non-sinusoidal flux density waveforms. A digital feedback program is developed in LabVIEW to trace hysteresis characteristics using measured voltages and currents. In this paper, magnetic characteristics and losses of Grain-oriented (GO) silicon steel and ferrite materials are obtained at different frequencies. Losses determined by calculating the area under the hysteresis loop are compared with measurements from a power analyzer. The proposed experimental setup can be used to characterize different materials at various frequencies.**

***Index Terms*— Hysteresis, ferromagnetic material, ferrites, LabVIEW, digital feedback.**

I. Introduction

Ferromagnetic materials are widely used in magnetic circuits and different parts of electrical machines and transformers [1]. They provide high permeable path for magnetic flux. These materials exhibit hysteretic and dynamic features in their magnetization process. Some materials like GO steels exhibit anisotropic behaviour [2]. In the design stage of machines, magnetic materials are tested to determine their losses and efficiency. In the design stage of machines, magnetic materials are characterized by modelling in Finite Element and circuit simulations to predetermine transient and steady state performance, losses and efficiency. The increase in the use of power electronic circuits results in magnetic flux with harmonics in the magnetic circuits. Hysteresis loss of a ferromagnetic material depends on magnetic flux density waveform [3]. Magnetic flux density with harmonics induces asymmetrical minor loops [3]; their position and the increase in loss due to these minor loops depend on the intensity and phase of harmonics. Steel manufacturers may not provide magnetic characteristics and loss in W/kg for different kinds of excitation. Thus a cost effective and a simple experimental setup is required to characterize the materials for different excitations. Traditional measurement methods based on analog circuits provide sufficient control over magnetic flux density waveform. But for higher values of magnetic flux density and two dimensional magnetic measurements, analog systems fail [4],

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[5]. Advancements in the field of computer and microprocessor technology help to develop digital feedback systems [6], [7], [8]. In most digital feedback setups, expensive commercial data acquisition (DAQ) systems are used. In this work, a cost effective product has been developed by using a micro-controller as a DAQ system.

In this paper, an experimental setup is developed to measure the magnetic characteristics of GO silicon steel and ferrite at different frequencies. A digital feedback program is developed in LabVIEW to measure hysteresis loops and calculate corresponding losses for sinusoidal and non-sinusoidal magnetic flux density waveforms. The measured secondary voltage and primary current are converted to magnetic flux density and magnetic field intensity respectively and a hysteresis loop is traced using the developed setup. The proposed system is very cost effective and can measure hysteresis characteristics for different harmonics. It is also possible to test samples of different shapes.

The paper is organized as follows. The proposed digital measurement system is presented in section II. Section III shows comparison between measurements carried out using the proposed setup and conventional measuring instruments. The paper is concluded in section IV.

II. Proposed Digital Measurement System Using LabVIEW

In this work, the desired flux density waveform inside a ferromagnetic material is generated inside the LabVIEW program. The corresponding voltage required to create the desired flux density waveform is calculated using the proportional controller developed in the program. The signal computed is amplified using a power amplifier. The PWM wave is generated in LabVIEW and is fed to an H-bridge inverter using a DAQ system developed using a TIVA controller. The primary voltage waveform calculated in LabVIEW is the control signal for the H bridge inverter. The amplified signal (output) of the inverter is fed to a magnetic Epstein tester. Its secondary voltage and primary current are fed back to LabVIEW using the DAQ system. The values of magnetic flux density (*B*) and magnetic field intensity (*H*) are calculated using the measured voltages and currents using Eqns. 1 and 2. The corresponding losses per cycle are calculated from the area under the hysteresis curve as given in Eqn. 3.

$$H = \frac{NI_{primary}}{l} \tag{1}$$

$$B = \frac{1}{NA}\int V_{secondary}dt \tag{2}$$

$$P = \int HdB \tag{3}$$

Here, l is the length of magnetic flux path, A is the cross sectional area of flux, N is the number of turns, $I_{primary}$ is the primary current, $V_{secondary}$ is the secondary voltage, B is the magnetic flux density, H is the magnetic field intensity, and P is the power loss in J/m^3. Figure 1 shows the block diagram of the proposed measuring system.

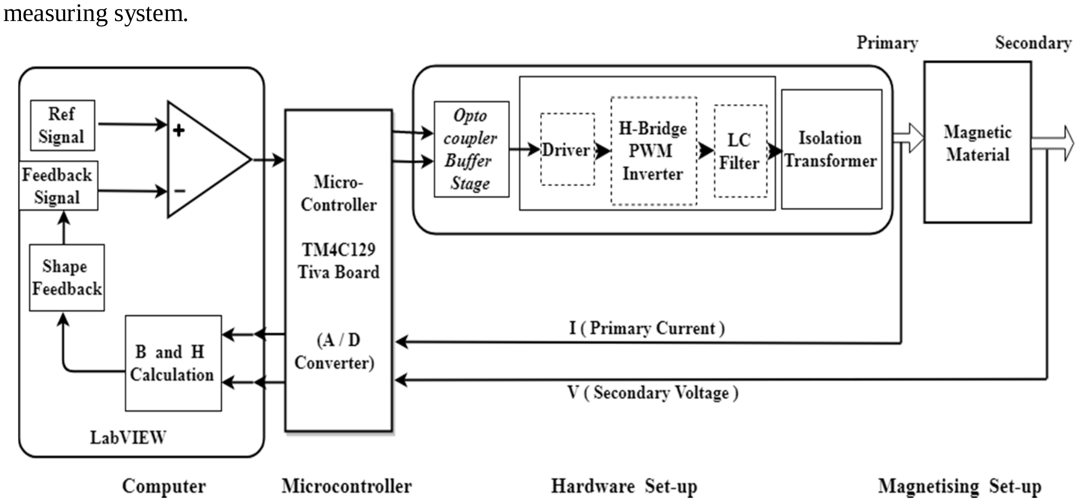

Figure 1. Proposed digital measurement system

A. Program Developed in LabVIEW:

The required waveform of flux density (peak flux density, frequency, harmonic components) inside the core is the input for the program. The expected primary voltage is calculated and the corresponding data is sent to the DAQ system. The secondary voltage and primary current data are fed back to the computer through the microcontroller. Using Eqns. 1 and 2, a LabVIEW environment is developed to calculate the desired *B*, *H* and loss values. The block diagram of the digital feedback controller logic implemented in LabVIEW is shown in figure 2.

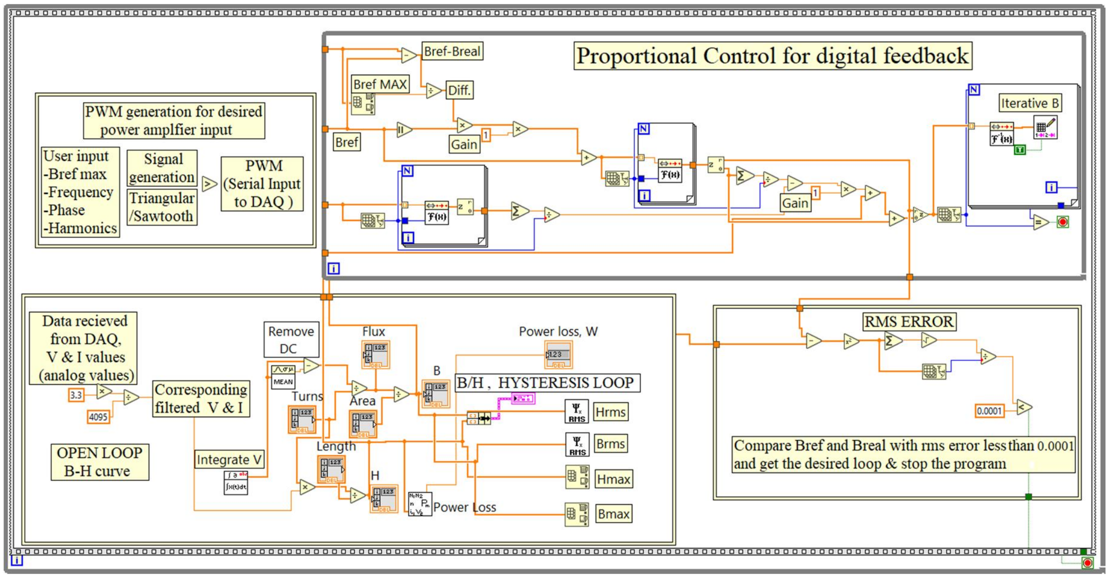

Figure 2. Simplified block diagram of the program written in LabVIEW

B. DAQ System

The DAQ system is accomplished using the Tiva C series TM4C129 microcontroller. PWM samples are generated in LabVIEW with 5 microseconds sampling rate and sent to the microcontroller for storing in its memory. The output of the controller is continuously being fed to the gate driver circuit of the inverter. The secondary voltage and the primary current of the magnetic tester sensed and further received by an ADC pin of the microcontroller sampled again at 5 microseconds. The received samples are stored in the controller's memory and then the samples are sent back to LabVIEW for implementing the digital feedback. Figure 3 shows the Tiva C series microcontroller.

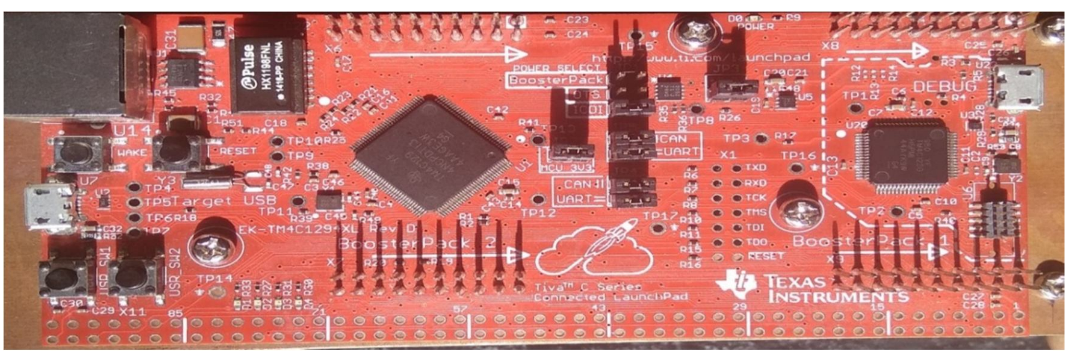

Figure 3. Tiva C series TM4C129 microcontroller

C. Power Amplifier

The H-bridge inverter amplifies the control signal fed from LabVIEW. The amplification of the signal depends on the value of the DC link voltage and the modulation index. The DC link voltage needs to be changed in accordance with the testing frequency. The schematic diagram of the H bridge circuit along with the gate drivers is shown in Fig. 4. The PWM signal generated from LabVIEW is given to input of the gate driver circuit IR2110. The output of the PWM inverter is fed to an LC filter to get the required control signal to excite the magnetic tester.

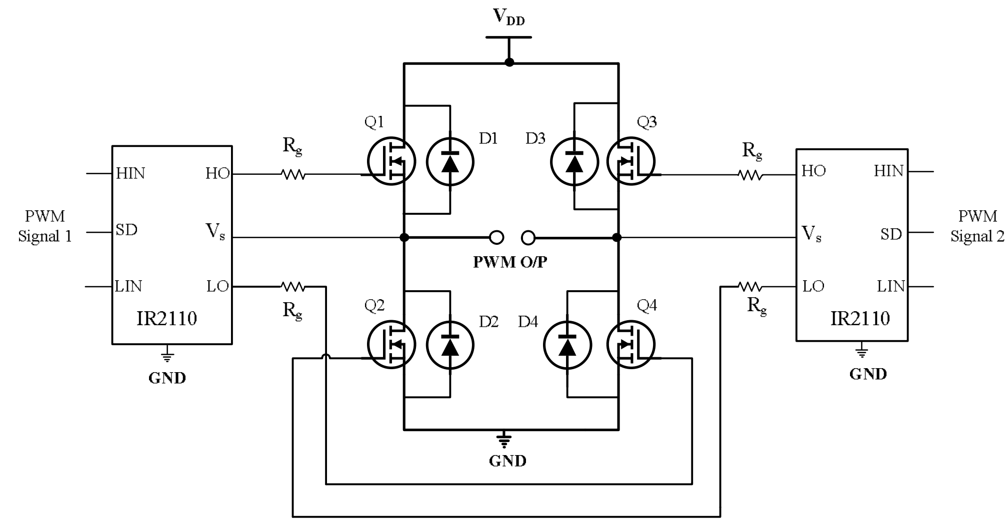

Figure 4. Schematic diagram of power amplifier

D. Measuring Setup

A standard Epstein frame is used to measure magnetic properties of soft magnetic materials. It consists of a primary winding and a secondary winding and the sample under test is inserted in form of strips. This is especially used to test laminated steel sheets. Magnetic characteristics of ferrites are measured using a low voltage high frequency ferrite core transformer. The voltage and current sensing circuits are shown in figures 5 and 6 respectively. The secondary voltage is received and attenuated with the help of a differential amplifier followed by a unity follower to give it to the input of the ADC. Similarly the current is obtained by measuring the voltage across a shunt resistor, which is then fed to an ADC pin after necessary attenuation. The voltage applied to the ADC pin should be between 0 and 3.3 V. The parameters of the differential amplifier are designed based on the secondary voltage and gain required to reduce the input voltage of the ADC pin to less than 3.3 V.

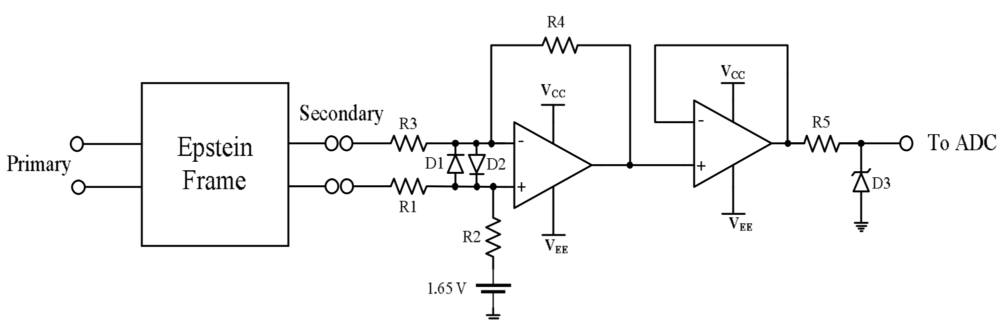

Figure 5. Voltage sensing circuit

Figure 7 shows the complete hardware set up of the implemented work. The measured voltage and current are displayed on an oscilloscope and compared with sensing circuit results in LabVIEW. The LC filter cut off frequency is decided based on the frequency of the excitation signal. The cut off frequency should be kept close to the signal frequency to get proper voltage and current wave shapes. For a frequency of 50 Hz, an inductor of 10 mH and a capacitor of 100 μF have been used.

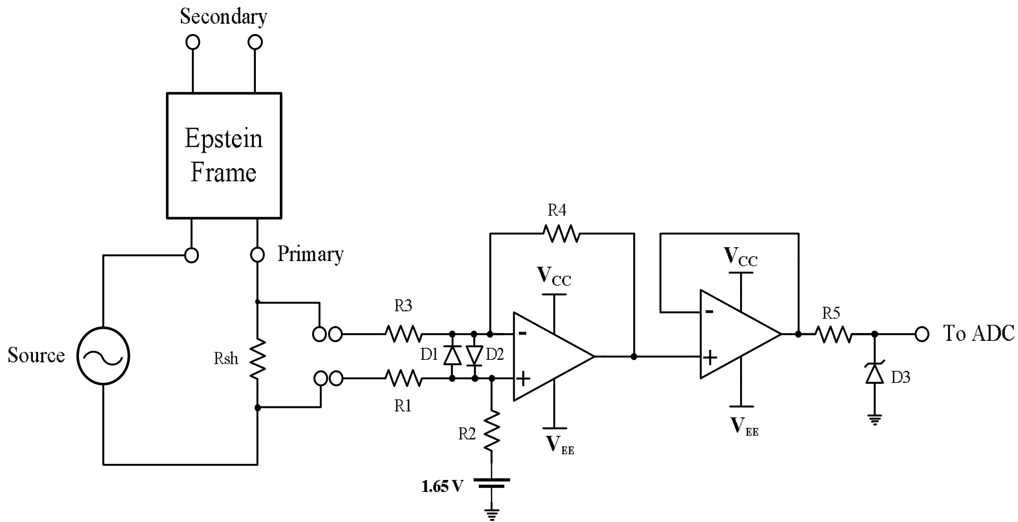

Figure 6. Current sensing circuit

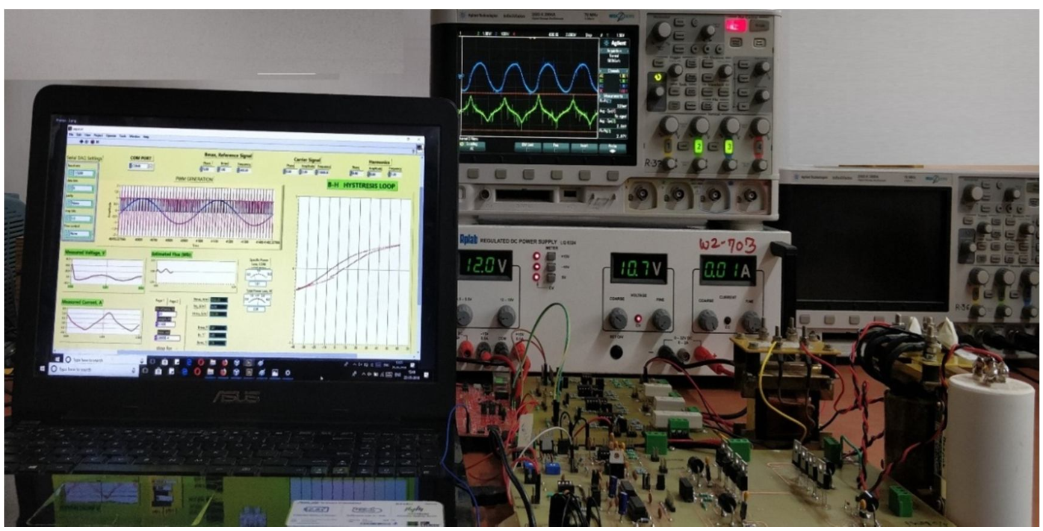

Figure 7. Experimental setup

III. Results

The front screen of the developed tool is shown in figure 8. The parameters such as maximum flux density (B_{max}), frequency, and phase of the reference signal need to be provided. In addition to this, the harmonic content in the reference signal can be varied. The measured voltage and current are displayed on the screen. The values of *B* and *H* are estimated and the hysteresis loop is plotted. The calculated flux waveform and loss are also indicated on the front panel. The BH loop obtained for GO steel sheets at 50 Hz from an Epstein frame is shown in figure 8.

The hysteresis curves obtained from an Epstein frame at 150 Hz and 200 Hz are shown in figure 9. As frequency increases, the loop bulges and results in increased losses. Figure 10 shows the hysteresis loops obtained from a 300 VA ferrite core transformer at 300 Hz and 400 Hz.

The presented results are obtained under open loop configuration, and contain small errors while retrieving the data. The close loop control is mandatory for accurate results and can be implemented in LabVIEW without additional hardware requirement. The error between desired and actual values of flux density would then be minimised along with phase compensation inside the software.

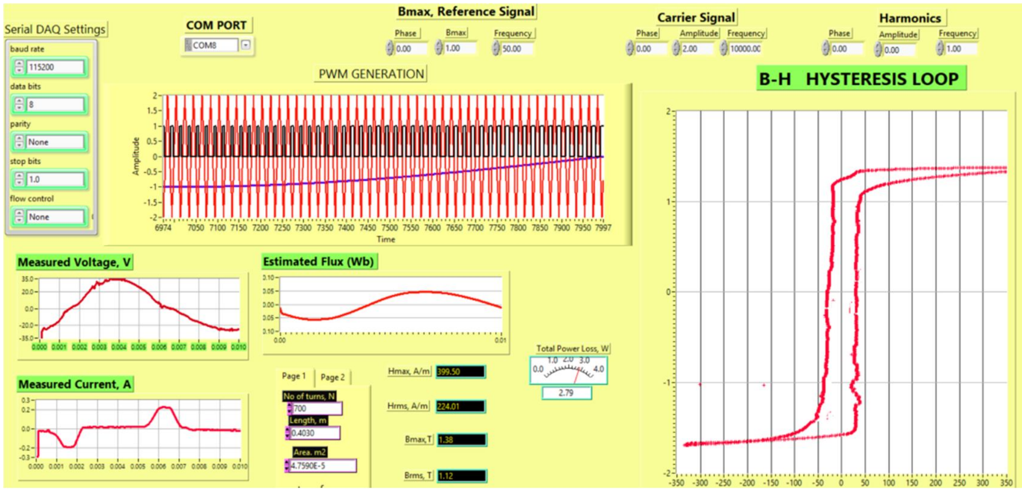

Figure 8. Front panel of developed tool in LabVIEW

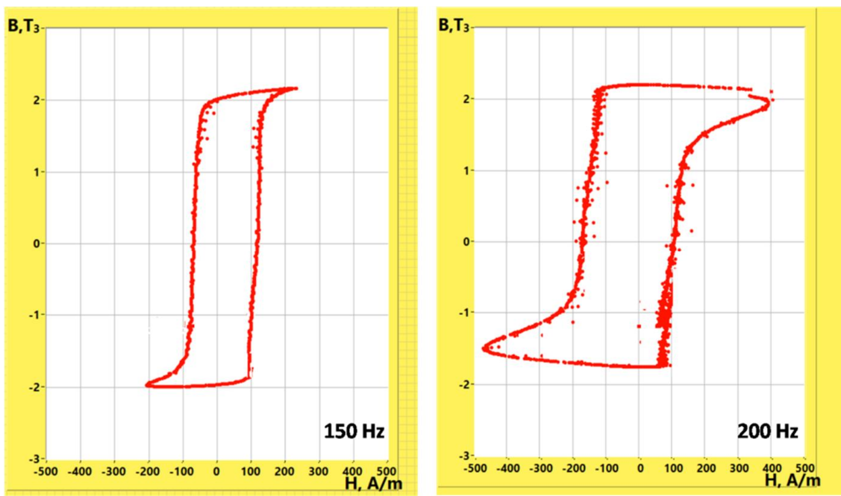

Figure 9. Acquired hysteresis curves at 150 Hz and 200 Hz (electrical steel)

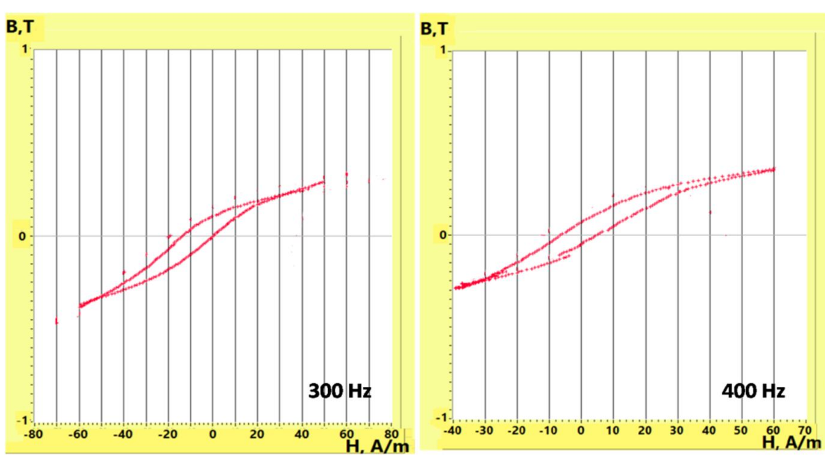

Figure 10. Acquired hysteresis curves at 300 Hz and 400 Hz (ferrites)

IV. Conclusion

A low cost LabVIEW based measuring tool is developed for characterization of soft magnetic materials. The developed tool is capable to analyze ferromagnetic materials with arbitrary flux density waveforms under various flux levels at different frequencies. This helps to assess performance of magnetic materials in different electrical apparatus. Measurements at frequencies up to1 kHz are possible with the current setup. The developed competence would help to make a comprehensive model to study hysteresis behaviour of magnetic materials under non-sinusoidal flux density waveforms. The closed loop control would be implemented to obtain smooth curves without distortions. This work could be modified to extend the frequency range of excitation waveform to measure magnetic characteristics at high frequencies. Further, the parameters of the Jiles-Atherton hysteresis model would be calculated via a genetic algorithm program developed in LabVIEW.

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References

[1] F. Fiorillo, L. R. Dupre, C. Appino, and A. M. Rietto, “Comprehensive model of magnetization curve, hysteresis loops, and losses in any direction in grain-oriented Fe-Si,” IEEE Transactions on Magnetics, vol. 38, 2002, pp. 1467-1476.

[2] P. S. Baghel, B. Sai Ram, K. Chwastek, L. Daniel, and S. V. Kulkarni, “Hysteresis modelling of GO laminations for arbitrary in-plane directions taking into account the dynamics of orthogonal domain walls,” Journal of Magnetism and Magnetic Materials, vol. 418, 2016, pp. 14-20.

[3] A. Benabou, J. V. Leite, S.Clénet, C. Simão, and N. Sadowski, “Minor loops modelling with a modified Jiles–Atherton model and comparison with the Preisach model,” Journal of Magnetism and Magnetic Materials, vol. 320, 2008, pp. e1034-e1038.

[4] W. Bolton, Control Engineering, Longman Scientific and Technology, 2nd edition, 1998, pp. 236–238.

[5] R. H. Bishop, Modern Control Systems Analysis and Design Using MATLAB®, Addison-Wesley, 1993, p. 152.

[6] A. Nafalski, T. Doan, and O. Gol, “Application of a virtual instrument concept in magnetic measurements,” Journal of Magnetism and Magnetic Materials, vol. 160, 1996, pp. 154–156.

[7] N. Derebasi, R. Rygal, A. J. Moses, and D. Fox, “A novel system for rapid measurement of high-frequency magnetic properties of toroidal cores of different sizes,” Journal of Magnetism and Magnetic Materials, vol. 215–216, 2000, pp. 684–686.

[8] S. Zurek, P. Marketos, T. Meydan, and A. J. Moses, "Use of novel adaptive digital feedback for magnetic measurements under controlled magnetizing conditions," IEEE Transactions on Magnetics, vol. 41, no. 11, 2005, pp. 4242-4249.