Measurement and Modeling of Anhysteretic Curves

S. A. Mousavi, A. Krings, G. Engdahl, and A. Bissal
Royal Institute of Technology (KTH)
Teknikringen 33, 10044 Stockholm, Sweden
E-mail : seyedali@kth.se

***Abstract*— This paper introduces a novel method for measurement of the anhysteretic curve based on controlled flux density waveform. The method improves the accuracy and on the other hand decreases the measurement time. Furthermore, the measurement on several grain-oriented and non-oriented materials have been performed by using both conventional and suggested methods. A comparison between the methods and modeling of anhysteretic curve are brought in the paper.**

***Index Terms*— Magnetic hysteresis, Magnetic materials, Electromagnetic modeling.**

I. Introduction

The anhysteretic curve of a ferromagnetic material constitutes the “ideal” magnetization curve of the material if it were perfect, in the sense that it has no defects or other deficiencies that hinder the magnetization and demagnetization process. To create accurate models that describe the magnetic hysteresis originated by the above mentioned causes, it is of great value to be able to distinguish between the intrinsic magnetization of the material itself and the magnetization effects that are caused by structural conditions and defects. In other words the anhysteretic curve shows the thermodynamic equilibrium state of ferromagnetic materials [].

This “ideal” so-called anhysteretic curve plays a vital role in the well-known hysteresis models such as the Jiles-Atherton [] and Bergqvist lag model [].

There are two methods for reaching a point on the anhysteretic curve, thermal and electrical. The thermal method that is described in [] is usually difficult to measure by it seems is more reliable method in the point of accuracy.

The ordinary electrical method used to reach each point of the anhysteretic curve involves subjecting the material to an alternating magnetic field that decreases gradually simultaneously with a superimposed bias DC field. The descending field must also start from a saturated state of the material. Therefore, by using a repeatable process the obtained points are independent of the previous memory of the material. Hence, the anhysteretic curve is a single valued function of the applied bias DC field. This method takes a lot of time, of the order of a couple of hours, to measure one point []. Besides the long time required, this leads to error in the measurement of flux density because of the existence of noise. Another problem is that the fast step-down near the final point can affect the accuracy of the measurement. This occurs because of the nonlinearity of the material and the H field control instead of controlling the B field. Also, the small offset of power supply is another source of error in this method.

This work presents a method based on a controlled flux density waveform instead of a magnetic field waveform to overcome these problems.

The applied waveform is a decreasing flux density waveform around a DC flux density instead of a DC magnetic field. This task can easily be performed using the introduced control algorithm.

II. Test Setup

The control algorithm described in [] is implemented on a National Instruments CompactRIO system consisting of a Power PC (NI-9022) running the LabVIEW real time operating system (RT System) and an FPGA (NI-9114) for controlling the I/O modules. A block diagram of the measurement setup is shown in Fig. 1.

The main power supply is a controllable current source, AE Techron 7224 power amplifier, which is controlled by an input voltage signal. The proposed control algorithm that is implemented in LabVIEW determines the input voltage that is fed into the power supply. The voltage is generated by an analogue output channel of a National Instruments DAQ card. The current is measured over a high precision shunt resistor of 1.2 Ohm connected in series with the excitation winding and the amplifier. The flux density is determined by a Lakeshore 480 Fluxmeter, which integrates the voltage of the measurement winding. The measured signals are used as the input of the control algorithm.

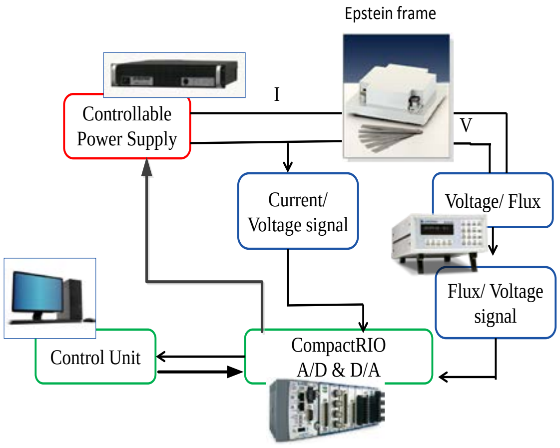

Fig. 1. The block diagram of the measurement setup.

III. Method of Measurement

As mentioned, applying descending alternating magnetic field around a bias DC field leads to a fast decrease of magnetic flux density near the anhysteretic point that causes uncertainty in the measured results. In this work a control algorithm is used

to keep the absolute value of rate of flux density, dB/dt, constant. This rate is chosen very low to remove the dynamic effects of hysteresis.

The applied waveform is a decreasing flux density waveform around a DC flux density instead of a DC magnetic field. One example of an applied B-field and corresponding H-field and hysteresis trajectory to obtain a point on the anhysteretic curve is shown in Fig. 2, Fig. 3, and Fig. 4, respectively.

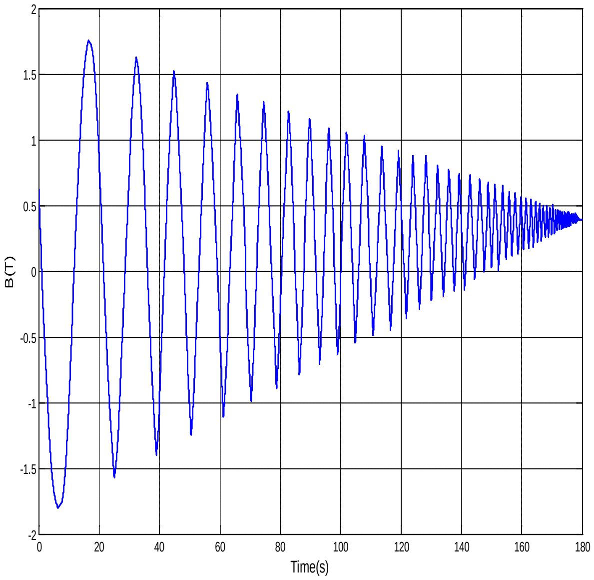

Fig. 2. B-field during measurement of anhysteretic point with 0.4 T DC offset of B by using the new method.

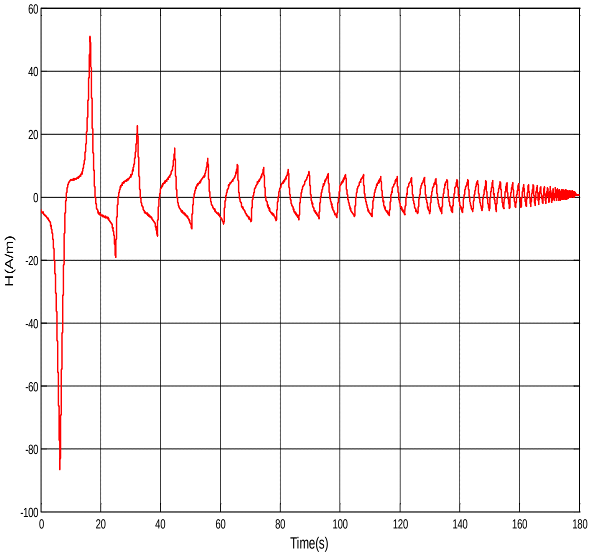

Fig. 3. H-field during measurement of anhysteretic point with 0.4 T DC offset of B by using the new method.

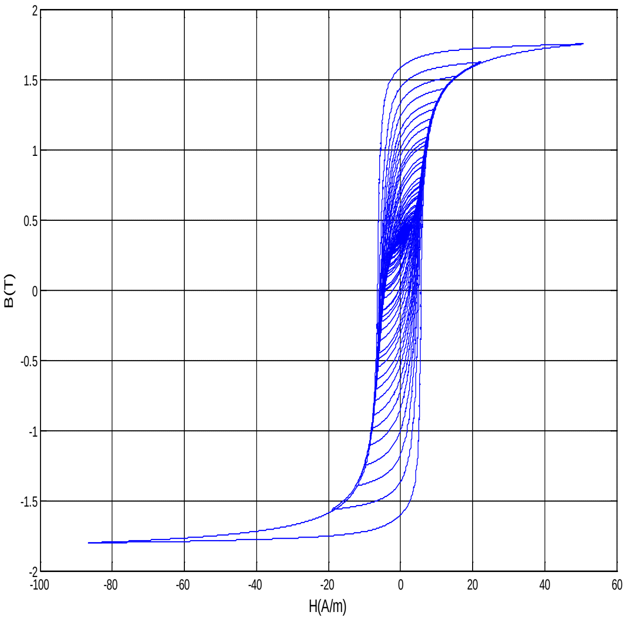

Fig. 4. Hysteresis loops during measurement of anhysteretic point with 0.4 T DC offset of B by using the new method.

IV. RESULTS AND DISCUSSION

The reliable method for the measurement of anhysteretic curve is using the thermal method. However, this method is very difficult in practice. Also, conventional electrical method is very time consuming and has some sources of error inherently. The proposed method in this paper brings an efficient solution for this problem. A discussion regarding accuracy of the suggested method will be done in the full paper. It would be theoretical and also with comparison of the results with other method. Furthermore, according to measured curves an improvement in the modeling of the anhysteretic curves will be presented.

REFERENCES

[1] J. Pearson, P. T. Squire, and D. Atkinson, “Which anhysteretic magnetization curve,” *IEEE Trans. on Magn.*, vol.33, no.5, pp. 3970-3972, 1997.

[2] J. V. Leite, N. Sadowski, P. Kou-Peng, N. J. Batistela, and J. P. A. Bastos, “Inverse Jiles-Atherton vector hysteresis model,” *IEEE Trans. on Magn.*, vol.40, no.4, pp. 1769-1775, 2004.

[3] D. Ribbenfjard, and G. Engdahl, “Modeling of Dynamic Hysteresis With Bergqvist's LagModel,” *IEEE Trans. on Magn.*, vol.42, no.10, pp. 3135-3137, 2006.

[4] R. G. Harrison, “Physical Theory of Ferromagnetic First-Order Return Curves,” *IEEE Trans. on Magn.*, vol.45, no.4, pp. 1922-1939, 2009.

[5] H. M. J. Boots, and K. M. Schep , “Anhysteretic magnetization and demagnetization factor in Preisach models” *IEEE Trans. on Magn.*, vol.36, no.6, pp. 3900-3909, 2000.

[6] S. A. Mousavi, “Electromagnetic Modelling of Power Transformers with DC Magnetization”, Licentiate thesis, Stockholm, Sweden, 2012.