Journal of ELECTRICAL ENGINEERING, VOL 55. NO 10/S, 2004, 91-92

EFFECT OF EXCITING FIELD WAVEFORM ATTRIBUTES ON QUASI-STATIC HYSTERESIS LOOPS

Elemír Ušák *

This paper is focused on the investigation of various exciting field as well as the flux density waveform attributes, such as the frequency, amplitude and especially the shape on the resulting hysteresis loops and associated magnetic parameters. The experiments have shown significant difference between two major cases – continuous and discontinuous waveform; moreover even in the case of continuous waveforms there are substantial differences between various magnetic parameters (*ie* complex power losses, complex permeability) evaluated from the measured waveforms resulting in the same hysteresis loop shape.

Keywords: hysteresis loop, magnetic parameters, power losses, complex permeability, relaxation effects

1 INTRODUCTION

The investigation of relaxation effects in SiFe materials revealed some interesting facts concerning the steady state after all the transients in the sample were faded out. Particularly, when the dynamic hysteresis loops are measured at various frequencies and in a chosen time instant the exciting field is kept at constant value H_i for sufficient time, the flux density starts to settle towards the steady-state value $B_{steady}(H_i)$, that was believed to be correspondent to the point lying on the quasi-static hysteresis loop with the value $B_{stat}(H_i)$, [1]. In contradiction with this assumption the steady-state flux density significantly differs from the expected value, as can be seen in Fig. 1. This discrepancy focused our attention to the measurement of quasi-static hysteresis loops by means of various methods with the aim to discuss the importance of relaxation effects even at relatively low field rates of change.

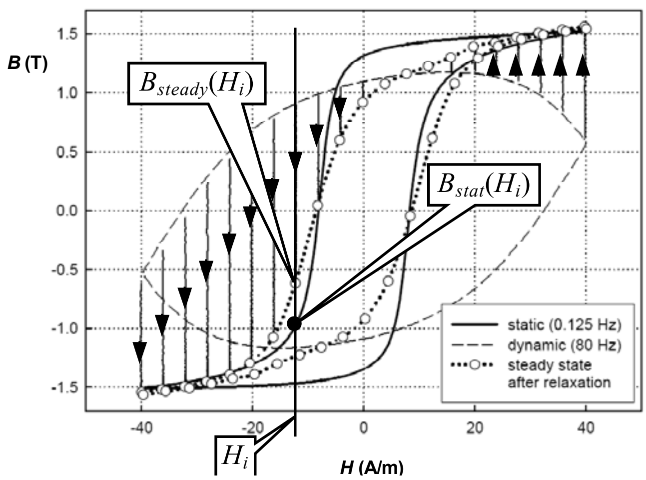

Fig. 1. The comparison of quasi-static, dynamic and steady-state relaxation hysteresis loops for triangular exciting magnetic field waveform. Also the settling of flux density from the dynamic loop to its steady-state value is shown. Similar behaviour was observed in case of sinusoidal waveform, too.

2 EXPERIMENTS AND DISCUSSION

The quasi-static hysteresis loops were measured with *continuous* triangular and sinusoidal waveform shapes as well as by *staircase-like* waveforms simulating classical approach using step-wise increasing and decreasing of the exciting magnetic field.

A conventional experimental arrangement consisting of an arbitrary waveform generator along with power amplifier and two identical digital voltmeters used for simultaneous sampling of the voltage drop across the standard resistor (proportional to the exciting field) and the voltage induced in the secondary winding was used for the measurement. For the dynamic measurements as well as the measurements with discontinuous waveforms the digital oscilloscope was used. In both cases the flux density waveform was obtained by numerical integration of the induced voltage. The upper frequency limit was given by the equality of hysteresis loop shape for any continuous exciting field waveform, meanwhile the lowest possible frequencies were determined by sufficiently high induced voltage levels, since any additional amplifier and/or integrator introduced unwanted offsets and drifts.

The examples of hysteresis loops obtained by various ways of measurement are shown in Fig. 2. Unlike the sinusoidal and triangular waveform resulting in the same hysteresis loop shape (dotted and dashed curves), the staircase-like loop (thick solid curve) significantly differs in the locations where the field jumps from one value to another − one can see the exponential-like relaxation towards the quasi-static values (open symbols), that are the same as in the case of continuous waveforms. On the other hand, the difference between these loops and the steady-state relaxation hysteresis loop (the same as in Fig. 1 – solid circles with thin solid line) obtained from the dynamic loop as described above is clearly visible.

The waveforms corresponding to the hysteresis loops from Fig. 2 are shown in Fig. 3a (continuous waveforms) and 3b (discontinuous waveforms). In the second case

* Slovak University of Technology, Faculty of Electrical Engineering and Information Technology, Department of Electromagnetic Theory, Ilkovičova 3, 812 19 Bratislava 1, Slovakia, E-mail: Elemir.Usak@stuba.sk

ISSN 1335-3632

there is an example of fine (40 steps per period) as well as coarse (80 steps per period) staircase-like waveforms.

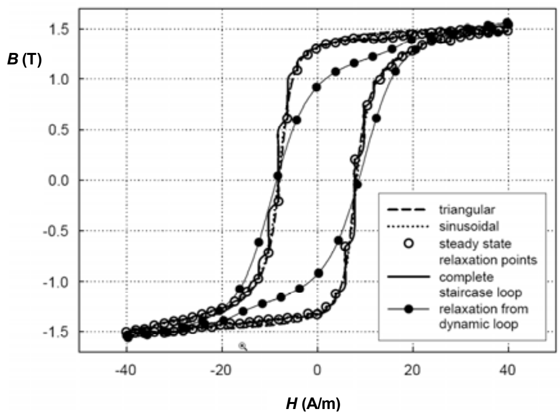

Fig. 2. The quasi-static hysteresis loops obtained by various measurement methods. Also the steady-state relaxation hysteresis loop obtained from dynamic loop is shown.

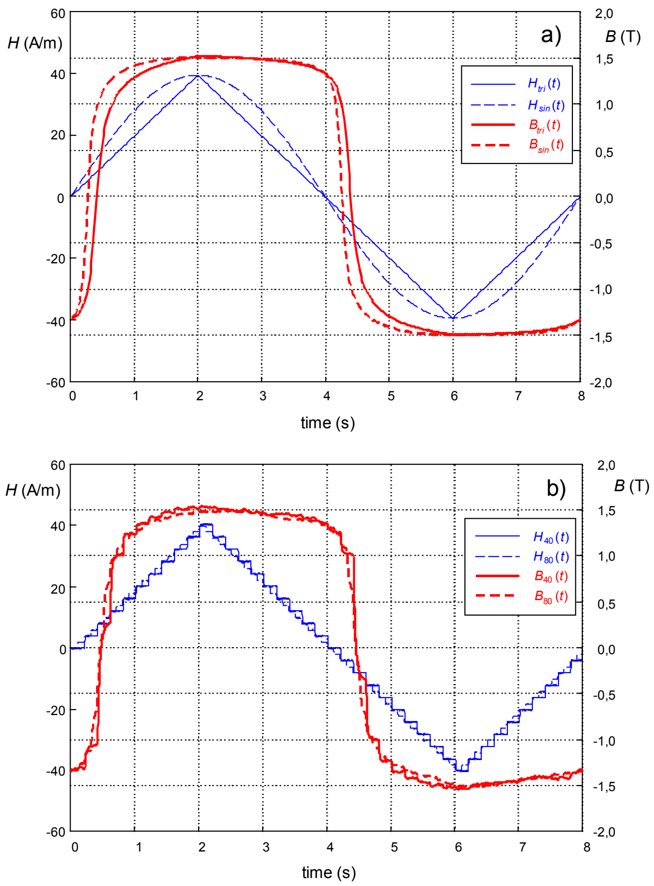

Fig. 3. The *continuous* (a) as well as *discontinuous* (b) waveforms of the exciting magnetic field strength (thin lines) and corresponding magnetic flux density (thick lines). In (b) the waveforms with 40 and 80 steps per period are shown.

3 CONCLUSIONS

The experiments described in this paper show a significant difference between the quasi-static hysteresis loops measured with *continuous* exciting field waveforms and measured by classical point-by-point method based on *step-wise changing* of the field. Note that in the second case the *actual* hysteresis loop area (given by thick solid line in Fig. 2) is larger than the *apparent* area corresponding to the points of the quasi-static loop measured by the conventional field-switching method (open symbols in Fig. 2) since the flux density changes related to the step in exciting field go outside of the loops measured with continuous signal. As a matter of this fact, the actual power losses are larger, than those expected from conventional measurements. From these experiments also follows the main conclusion, that any rapid change of the exciting field resulting in the discontinuity should be avoided.

Another issue was previously discussed in [3], where the significant influence of the waveform shape on various magnetic parameters calculated from the waveform spectra (complex power losses and complex permeability) is pointed out. Even if the shape of hysteresis loops was the same (*for continuous sinusoidal exciting field as well as sinusoidal flux density*), the imaginary component of the complex power as well as both components of the complex permeability exhibit significant differences depending on waveform shape.

Acknowledgement

This work was supported by Scientific Grant Agency of the Ministry of Education of the Slovak Republic (VEGA), grants No. 1/0142/03 and 1/0143/03.

REFERENCES

[1] KRIVOŠÍK, P. – UŠÁK, E.: Domain Wall Motion and Rate-Dependent Hysteresis in Metallic Ferromagnets. Journal of Electrical Engineering 53 No 10/s. (2002) 84-86

[2] UŠÁK, E. – KRIVOŠÍK, P.: Hysteresis and Eddy Current Relaxation in SiFe Materials, to be published in Czechoslovak Journal of Physics

[3] UŠÁK, E.: The Measurement of Magnetisation Curves with Defined Flux Density Waveform at Low Frequencies. Journal of Electrical Engineering 53 No 10/s. (2002) 77-79

Received 20 July 2004

Elemír Ušák (Assoc Prof, PhD), born in Nižná pri Piešťanoch, Slovakia, 1965. Graduated from the Faculty of Electrical Engineering, Slovak technical University, Bratislava in Solid State Physics branch, 1988 and received the CSc (PhD) degree in Theory of Electromagnetism in 1996. After habilitation in 2000 he became an associate professor at the Department of Electromagnetic Theory FEI STU.