Characterization of soft magnetic materials under arbitrary DC-bias conditions

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Characterizations of soft magnetic materials under DC-bias conditions are ambiguously defined due to their dependence on previous magnetization states and the limitations in measuring the DC component of the polarization. A measurement method based on an arbitrary J waveform is introduced, combining a symmetric low frequency major loop and a pair of higher-frequency not-centred minor loops. This method is then applied to investigate the evolution of loss and DC-biased minor cycles for various positions in the *(H,J)* plane. Such characterizations can be applied to map the magnetic loss corresponding to the minor loops, as a function of their frequency, amplitude, displacement and history.

Keywords: Magnetic measurements; DC-bias; Magnetic loss; Electrical steels; Ferrites

1. Introduction

The estimation of the core loss corresponding to a small hysteresis loop under a significant and intentional DC offset is necessary for many applications, especially converter cores or inverter-driven motors. Measurement standards only cover centred sinusoidal polarization and provide no guidelines for such DC-biased characterizations. Typically, however, they are done through the injection of a DC current I_{dc} in a dedicated winding. In this case, while the magnetic field offset H_{dc} is easily determined, the measurement of the polarization offset J_{dc} requires continuous integration of the induced voltage, which is hardly achievable with adequate accuracy. To circumvent this issue, methods adding one or more fast minor loops on a slow sinusoidal major loop were introduced in the literature, either by adding sinusoidal variation at the tip of the loop [1-2] or symmetric pulses at arbitrary points [3].

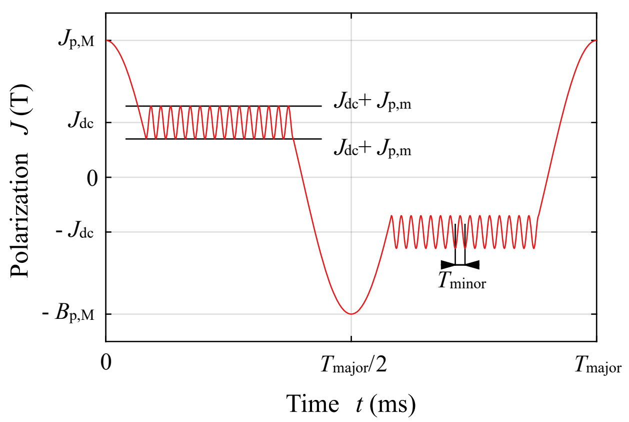

Figure 1: Illustration of the reference waveform for the J-bias measurement method.

In this paper, a more flexible method is considered, based on the insertion of multiple minor loops of amplitude $J_{p,m}$ and duration T_{minor}, inside a major loop of amplitude $J_{p,M}$ and duration T_{major}. As illustrated in Figure 1, the major loop can be interrupted at any point to set the polarization offset J_{dc}. The repetition of the minor loop allows to reject circuit transient and relaxation effects, and improve the decoupling between the dynamic effect of the major and minor loops. This allow to choose a moderate value for the ratio $T_{major}/T_{minor} = f_{minor}/f_{major}$ (e.g., 20 in the Figure 1) without impacting the minor loops.

2. Results and discussion

The described method was applied on Fe-(3wt%)Si laminations and on MnZn ferrite (N30), for different combinations of the polarization parameters (J_{dc}, $J_{p,m}$, $J_{p,M}$). As demonstrated in Figure 2, varying $J_{p,M}$ (i.e., changing the magnetic history) moves the minor cycle horizontally in the *(H,J)* plane. The behaviour of the loss for multiple sets of these parameters is studied as a function of the frequency.

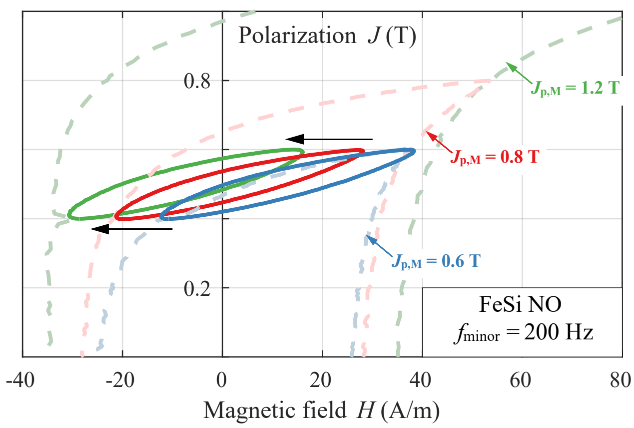

Figure 2: Example of DC-biased hysteresis loops (solid lines) with the same bias $J_{dc} = 0.5$ T and amplitude $J_{p,m} = 0.1$ T. The loops move horizontally due to different $J_{p,M}$ (dashed lines). FeSi NO, $f_{minor} = 200$ Hz.

Additionally, measurements under injected DC current were conducted to provide a comparison of the applicability, accuracy, and results of the two methods.

References

[1] H. Okama *et al.*, J. Magn. Magn. Mater. **505** (2020), 166688.
[2] O. de la Barrière *et al.*, IEEE Trans. Ind. Electron. **64** (2017), 2522-2529.
[3] M. Luo *et al.*, IPEC-Niigata 2018 -ECCE Asia, (2018), 422-427.

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