Tangential Field Coils for Analyses of Soft Magnetic Materials – A Systematic Comparison of Methodologies

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As early as in 1988, the IEC discussed the application of tangential field coil (H-coil) for physically more correct SSTs. The reason was the starting insight that the calculation of the magnetic field strength $H(t)$ from the magnetization current $i(t)$ by a nominal path length L_N involves a systematic source of error that impedes correct loss determination, a priori. However, the H-coil should be arranged in zero-distance from the sample distance. We present here a coil design that fulfills the corresponding demands in acceptable ways. This is attained by an incompressible H-coil of minimum thickness, extreme coil area and elastic on-press to the sample surface.

Keywords: tangential field coil, single sheet tester, demagnetizing fields, printing technology, soft magnetic sheets

1. Introduction

The aim of magnetic Single Sheet Testers (SST) is to measure energy loss and other characteristics of magnetic sheets with highest grades of accuracy and reproducibility. However, the IEC-standardized SST [1] shows an a-priori systematic source of error: The magnetic field strength H is not measured in direct ways. Rather it is assumed that it is proportional to the magnetization current i. However, exact proportionality is not existing, since the given magnetic circuit is not homogeneous. In particular, the yoke and its contact regions exhibit distinct inhomogeneity, with loss that cannot be neglected.

Already in 1988, the IEC considered the application of a tangential field coil for physically more correct SSTs [2], as also suggested by ourselves in [3]. Common insight started that the calculation of field $H(t)$ from $i(t)$ by a nominal path length L_M involves a systematic error that impedes correct loss determination, a priori. But as a crucial demand, the H-coil should be arranged in zero-distance from the sample distance, without being sensitive to compression and temperature.

But even todays standardization lacks from the following:

- The standard Epstein Test [4] still uses constant $L_M = 94$ cm.
- The standard SST [1] uses constant $L_M = 45$ cm.
- A newly proposed „advanced“ SST [5] proposes a compressible H-coil of rather high mean, effective distance, analogous to the AR-SST [6] for amorphous ribbon.

2. Results from H-coils and their discussion

The H-coil should detect the field H with zero distance d from the surface of the studied sample of the material [7,8]. H rises with smallest d [7,8], according to a theoretical interpretation, as based on “magnetic charges” [9,10].

However, zero effective distance d =>0 of the effective coil centre is not feasible due to many parameters, including signal sensitivity of the coil. Thus, in practice, about $d = 2$ mm up to 3 mm is the usual compromise – a source of systematic error.

In todays practice, three types of H-coils are applied:

a) *Wound H-coils* -They are made of thin wire (> 30 μm) on a thin nucleus (> 500 μm) – yielding high turn density *TD* round 20/mm for a single-layer coil. However, inacceptable low test stability is given, since d of a compressible individual turn is not constant - time deviations Δd arise through air gap between nucleus and wire, and due to various impacts (mechanical, thermal, ageing, moisture, manufacturing tolerances, etc.)

b) *PCB-printed H-coils*, as favored by the authors - a novel tendency. From 35 μm flat conductive band on > 1 mm plastic nucleus – showing high stability due to non-compressibility (Δd => 0). However, *TD* tends to be low, close to ca. 2 / mm.

c) *3D-printed coil,* as prototypes [11]– even thinner nucleus. But manufacturing is complicated, since complex multi-nozzle printers are rare.

3. Novel Achievement of most minimal-distance H-coil

In the last years, we developed a novel design that satisfies all aforementioned aspects by the following features:

(a) The printed coil is incompressible, as a novelty for SSTs.
(b) Its favored sum thickness is about 1.5 mm.
(c) Its surface area is e.g. 30 cm x 17 cm ≈ 500 cm² [10] or even e.g. 30 cm x 48 cm ≈ 1400 cm² [12] exceeding usual values distinctly.
(d) Its mean distance from the sample is < 1mm, below usual values. The latter can be achieved with an elastic load layer that reduces air gaps between coil and sample to a minimum, especially in cases of waviness of the samples.

References

[1] IEC Standards 60404-3, Single sheet tester, (1992).
[2] Revision of IEC Public. 404-3, Draft IEC 68(Sec)59, (1988).
[3] H.Pfützner, P.Schönhuber, IEEE Trans. Magn. **27-2**, (1991), 778-785.
[4] IEC Standards 60404-2, Epstein tester, (1996).
[5] IEC proposal Advanced SST with H-coil, (2023).
[6] European Standard, Amorphous SST, EN IEC 6040 4-16, (2018).
[7] H.Pfützner, PhD, Vienna University of Technology, (1978).
[8] T.Nakata, Y.Kawase, M.Nakano, IEEE Trans.Magn, vol. Mag-**23, No. 5**, (1987), 2596 – 2598.
[9] F.Fiorillo, Measurements and Characterization of magnetic materials, Elsevier Academic Press, (2004).
[10] H.Pfützner, G.Shilyashki C.Bengtsson, AIP Adv.**12**, 105208, (2022).
[11] G.Shilyashki, H.Pfützner, M.Giefing, E.Huber, IEEE Trans.Magn.**56-7**, 6000505, 2020.
[12] G.Shilyashki, H.Pfützner, C.Bengtsson, E. Huber, IET El.Power Appl.;**16-5**, elp2.12173, (2022), 525–535.