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Journal of Materials Processing Technology 108 (2001) 221–224

Journal of Materials Processing Technology

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Measurement of magnetostriction and magnetic properties in an open magnetic circuit

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Abstract

In order to measure a.c. magnetostriction and a.c. magnetic properties of magnetic sheet samples, an open circuit magnetizing system, which has a pair of magnetic exciting coils, has been constructed to realize uniform magnetization over a considerably large area in the sample. We measured magnetostriction by a Michelson interferometer using He–Ne laser and measured B–H properties by a B coil, double H coils and a compensation coil. Thus, magnetostriction and magnetic properties can be measured simultaneously under a defined magnetizing condition without external constraint by yokes. © 2001 Published by Elsevier Science B.V.

Keywords: Open magnetic circuit; Single sheet tester; Michelson interferometer

1. Introduction

Low a.c. magnetostriction of electrical steel sheet is the most relevant factor to reduce core noise in transformers. For magnetostriction measurements, strain gauge method has long been applied but it measures in a limited area and also needs some skills to get accuracy and repeatability. Recently, optical methods have been applied to measure averaged magnetostriction in a larger area in specimens like a laser Doppler vibrometer [1] and so on. One of the authors has also reported a measuring system by a Michelson interferometer using He–Ne laser [2]. An open magnetic circuit will be able to avoid constraint by yokes or magnetizing vibration due to the contact of specimen ends and yokes in a single sheet tester (SST) which would influence the accuracy of magnetostriction. A pair of magnetizing coils with an air gap enables to realize the uniform magnetization over a considerably large area in the center of the sample [2]. In this paper, we have constructed an SST with open magnetic circuit, which enable to measure B–H properties, magnetic loss and magnetostriction simultaneously.

2. Measuring system

A diagram of the detecting device of magnetostrictive strain is shown in Fig. 1. Optical system is a modified Michelson interferometer. Mirrors M_1 and M_2 are set to the uniform magnetization part of specimen with a distance of $L = 200\,\text{mm}$. A light source is a He–Ne Laser with a wavelength $\lambda_L = 633\,\text{nm}$. Since interference fringes are caused from the difference of optical path lengths between half mirrors HM_1 and HM_2, they remain invariant with the displacement of the position of specimen. Photo-sensor 1 and 2 are set at the points apart mutually $\pi/2$ different phase angle of the lightness of interference fringes if they could vary sinusoidally with place. Lissajous figure obtained by the signals $P(t)$ and $Q(t)$ from two photo-sensors was utilized to count the fringe movement, and magnetostriction λ is given by

$$\lambda(t) = \frac{\Delta L(t)}{L} = \frac{\lambda_L}{4\pi L}\left\{\tan^{-1}\frac{Q(t)}{P(t)} + 2N\pi - \tan^{-1}\frac{Q(0)}{P(0)}\right\} \quad (1)$$

where N is the number of light lines passing the point of photo-sensor 1. We can get magnetostriction of 10^{-10} order theoretically by use of 14-bit wave memory to process the signals $P(t)$ and $Q(t)$.

Open magnetic circuit is adopted so as to make the specimen free from any external forces. Fig. 2 shows schematic diagram of measuring tester which is constructed from an open magnetic circuit with a pair of exciting coils, a B coil, double H coils and a compensation coil. A separation between the two exciting coils enable to widen uniform magnetizing condition range over the center of sample. No additional exciting coils to compensate waveform distortion were applied to simplify measurement procedure.

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PII: S0924-0136(00)00759-7

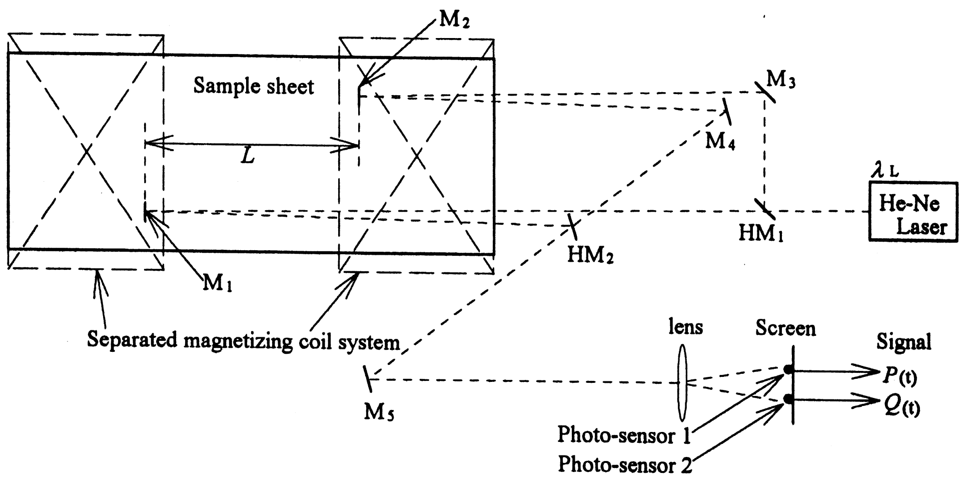

Fig. 1. Diagram of the detecting device of magnetostrictive strain.

3. Experimental results and discussions

SST samples of 500 mm long and 100 mm wide non-oriented (50A270) and grain oriented silicon steel sheets (35P, 35G) and Fe based amorphous ribbons (2605S-2) were experimented. Examples of magnetic induction distribution in the specimen 50A270 are shown in Fig. 3. B distribution was within 1% in 120 mm in the middle of samples, for 50A270 at $B_m = 1.0-1.5$ T and for 35P and 35G at $B_m = 1.6-1.85$ T, respectively. The waveform distortion rate distribution was within 2%.

Magnetic field strength H and magnetic induction B are sensed at 45 mm apart from the center of samples along the longitudinal direction where the most uniform H and B

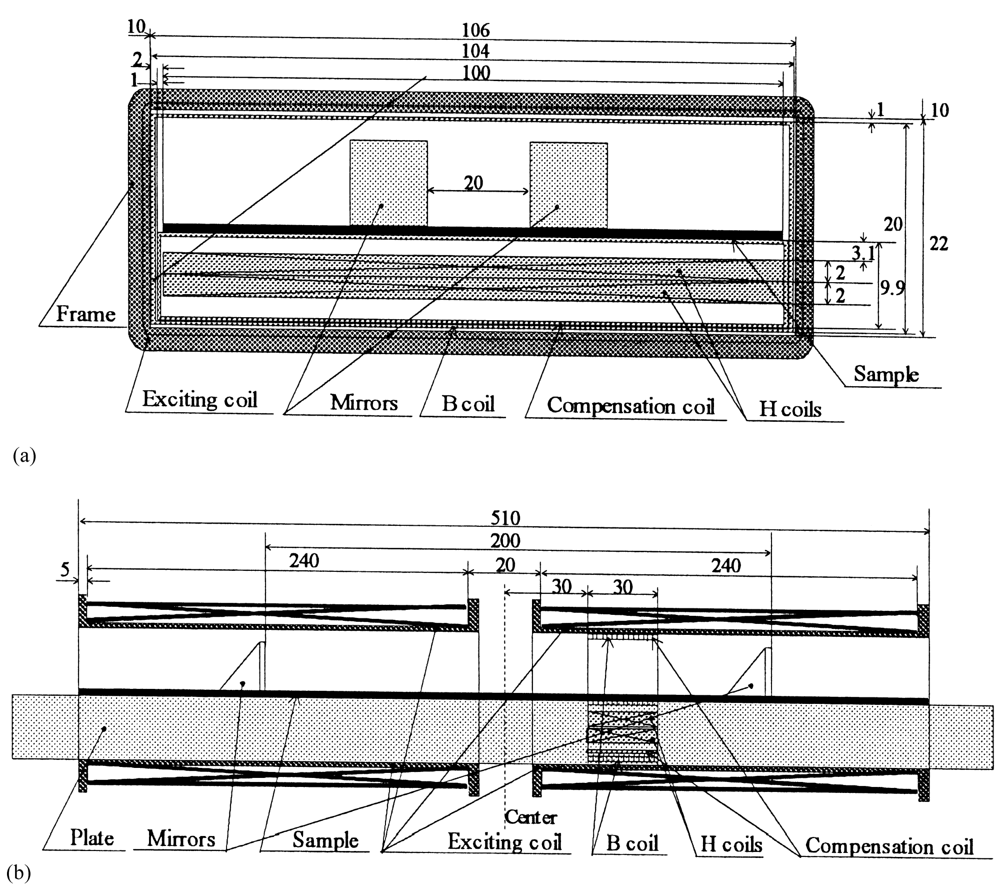

Fig. 2. Schematic diagram of measuring tester: (a) vertical cross-section; (b) horizontal cross-section.

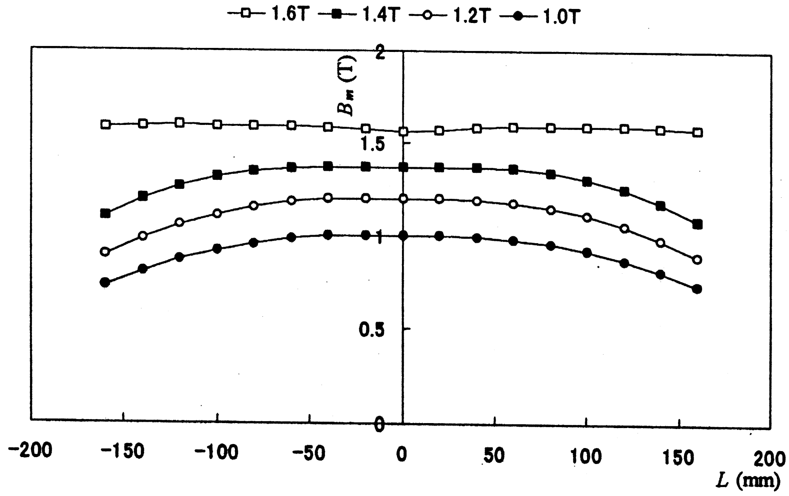

Fig. 3. Distribution of B (50A270, $f = 50$ Hz).

distributions are obtained. Since H decreases linearly with distance from the surface of samples due to demagnetization field, double H coil method was applied to obtain the effective field of samples. B coil was wounded just inside the exciting coil and a compensation coil was employed to cancel the magnetic induction outside samples through the B coil.

The samples were also experimented in the conventional SST (closed type SST) to compare magnetic properties as shown in Fig. 4. The discrepancy between the two methods was less than 3% in B–H and loss properties. The open magnetic circuit measurement needed to pay no attention for biased magnetization whereas the conventional SST showed a little biased magnetization due to yokes even after the neutralization. The open magnetic circuit has the advantage to measure samples of very thin amorphous ribbons that would be easily constrained at the yoke or to measure a curved sheet of which ends have gaps between yokes. Besides, a separation between the pair of exciting coils had advantage of not only widening uniform magnetizing condition range but also having the possibility of measuring magnetostriction in width direction of a sample. Fig. 5 shows examples of B–H loop and B–λ loops of 50A270 in which λ_l and λ_w are magnetostriction along the longitudinal direction and width direction of the sample, respectively.

4. Conclusion

An open magnetic circuit magnetizing system with a pair of exciting coils was concluded to enable to measure

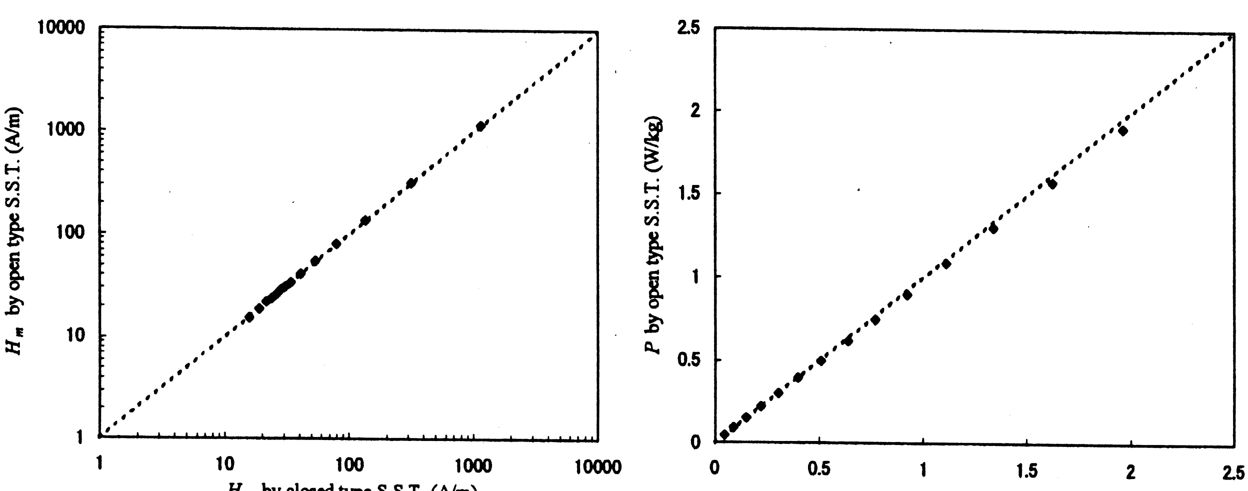

Fig. 4. Comparison of results obtained from open type and closed type SSTs (50A270, $f = 50$ Hz).

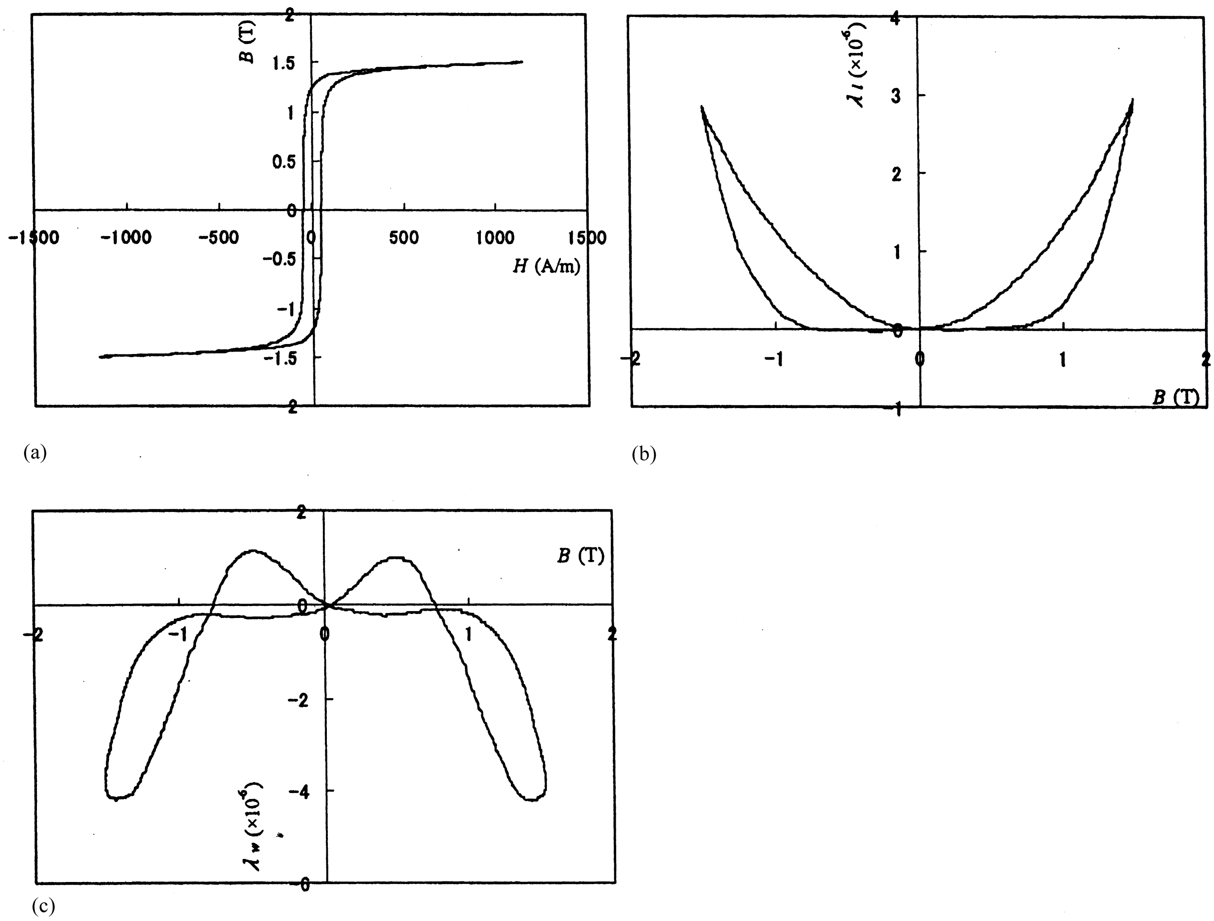

Fig. 5. Example of B–H loop and B–λ loop (50A270, $f = 50$ Hz).

magnetic properties with accuracy comparable to the conventional SST. Besides, magnetostriction along the longitudinal and wide direction of the sample can be measured simultaneously with magnetic properties under a defined magnetizing condition without external constraint by yokes.

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