

*Physics*

*Electricity & Magnetism fields*

---

Okayama University

Year 1999

---

Single sheet tester having open magnetic  
path for measurement of  
magnetostriction of electrical steel sheet

Tomoya Nakase  
Okayama University

Koji Fujiwara  
Okayama University

Masanori Nakano  
Okayama University

Norio Takahashi  
Okayama University

This paper is posted at eScholarship@OUDIR : Okayama University Digital Information Repository.

[http://escholarship.lib.okayama-u.ac.jp/electricity\\_and\\_magnetism/23](http://escholarship.lib.okayama-u.ac.jp/electricity_and_magnetism/23)

# Single Sheet Tester Having Open Magnetic Path for Measurement of Magnetostriction of Electrical Steel Sheet

Tomoya Nakase, Masanori Nakano, Koji Fujiwara and Norio Takahashi

Department of Electrical and Electronic Engineering, Okayama University, 3-1-1 Tsushima, Okayama 700-8530, Japan

**Abstract** — A single sheet tester having closed magnetic path (a closed type of SST) has a problem that measurement accuracy of magnetostriction is considerably affected by electromagnetic force between specimen and yoke. Therefore, an open type has been developed. In order to get uniform flux distribution in sufficiently large region, a compensating magnetizing winding is installed, and a method of waveform control is investigated, in which applied voltages to main and compensating windings are adjusted individually. The effectiveness of the newly developed open type is demonstrated by measuring magnetostrictions of thin amorphous sheet as well as highly grain-oriented silicon steel sheet.

**Index Terms** — amorphous metal, laser Doppler vibrometer, magnetostriction, silicon steel, single sheet tester

## I. INTRODUCTION

A closed type of SST is widely used in the measurements of magnetic properties such as magnetostriction as well as magnetization curve and power losses of electrical steel sheets [1]–[3]. However, the measurement accuracy of magnetostriction is very sensitive to the electromagnetic force between specimen and yoke [3]. Although an open type of SST having a single magnetizing winding is proposed to overcome such a difficulty, the uniformity of flux distribution is not sufficient [4].

In this paper, an open type of SST having main and compensating windings, which are excited individually, is proposed. The construction and feature of the proposed open type are described, and a technique for making the flux distribution uniform by controlling the applied voltages of both windings is discussed. The magnetostriction measurements obtained from the open and closed types are compared.

## II. SINGLE SHEET TESTER HAVING OPEN MAGNETIC PATH

Figure 1 shows the newly developed open type. As shown in Fig. 1(a), the compensating winding is wound at the edges of main winding to get the uniform flux distribution. The length (430 mm) and width (103 mm) of main winding are determined so that a specimen of 500 mm × 100 mm shown in Fig. 1(b) can be used, which is also available for the JIS (Japanese Industrial Standards) SST [2]. The compensating winding is composed of three layers of different lengths (80, 60, 40 mm) and they are connected in series. The configuration of windings is determined with the help of magnetic field analysis. As the main and compensating windings are excited individually, supplemental power amplifier, matching transformer and attenuator are added in an excitation part of the measuring system for the closed type [3] as shown in Fig. 2. In a data acquisition part, a scanning switch is also added, because flux densities at two positions

in specimen are detected by using two of B-coils wound directly on specimen as shown in Fig. 1(b) for waveform control described below.

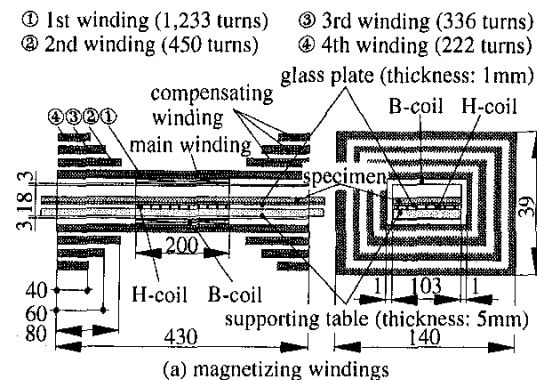


Fig. 1. Single sheet tester having open magnetic path.

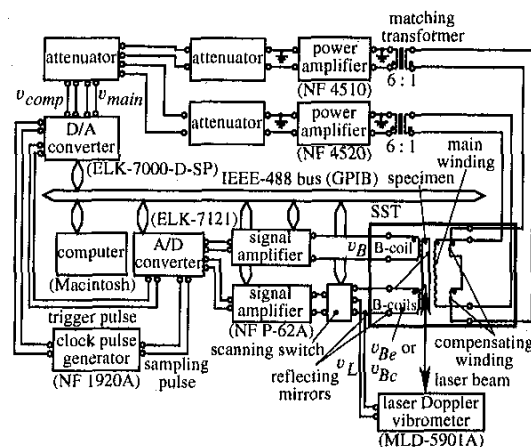


Fig. 2. Digital measuring system.

## III. METHOD OF WAVEFORM CONTROL

In order to establish a method of waveform control, the flux distribution in specimen is examined. Figure 3(a) shows the effects of the amplitude  $V_{main}$  of voltage  $v_{main}$  of main winding on the maximum value  $B_m$  and the phase angle  $\theta_B$  of flux density when the amplitude  $V_{comp}$  of voltage  $v_{comp}$  of compensating winding and the phase difference  $\phi_v$  between  $v_{main}$  and  $v_{comp}$  are fixed. Both  $B_m$  and  $\theta_B$  increase with increase

Manuscript received March 5, 1999.

T. Nakase, M. Nakano, K. Fujiwara and N. Takahashi, Tel: +81-86-251-8115, Fax: +81-86-251-8258, E-mail: {nakase@3dlab, nakano@eplab, fujiwara@eplab, norio@eplab}.elec.okayama-u.ac.jp.

of  $V_{main}$ , and the change rates of both quantities at the center are larger than those at the edge. The effects of  $V_{comp}$  and  $\phi_0$  are also measured as shown in Figs. 3(b) and (c). The tendency of obtained results can be summarized as shown in Table I. A method of waveform control is developed based on these results.

Figure 4 shows the flow chart of proposed method of waveform control. At the process ①,  $v_{main}$  is adjusted so that  $B_c$  and  $B_e$  can be equal to each other, where  $B_c$  and  $B_e$  are the maximum flux densities at the center and the edge, respectively. At the process ②, the waveform  $b_e$  of flux density at the edge, which is less sensitive, is controlled so as to be sinusoidal by adjusting  $v_{main}$ . When  $v_{main}$  is adjusted, the waveform of flux density approaches to the sinusoidal one in wide region as well as the specified position. At the process ③, the waveform  $b_c$  at the center, which is more sensitive, is controlled so as to be sinusoidal by adjusting  $V_{comp}$ . These processes are iterated until specified convergence criteria shown in Table II are satisfied at each process.  $\epsilon_B$  and  $\epsilon_{FF}$  are the errors of the maximum flux density and form factor  $FF$  of induced voltage, respectively.  $\Delta\theta_B$  is the phase difference between  $b_c$  and  $b_e$ . By using the proposed method of waveform control, the sufficient uniformity can be realized in the range of 200 mm in terms of the maximum flux density and the phase.

Figure 5 shows the initially and finally applied waveforms of  $v_{main}$  and  $v_{comp}$ . B1 and B6 coils shown in Fig. 1(b) are adopted to control the flux waveforms. A highly-oriented silicon steel sheet (JIS 27P100, thickness: 0.27 mm,  $W_{17/50}$ :  $\leq 1.00$  W/kg) is used as a specimen.  $B_m$  and frequency  $f$  are set at 1.9 T and 50 Hz, respectively. There is a large difference between the final waveforms of  $v_{main}$  and  $v_{comp}$ . Although another measurement is also carried out by using B8 instead of B6, the similar results are obtained. It is understood that the maximum flux density of the open type is large enough compared with the closed type.

#### IV. RESULTS AND DISCUSSION

Figure 6(a) shows the comparison of magnetostrictions of silicon steel sheet (27P100) obtained from the open and closed types with various conditions. The frequency is 50 Hz. The magnetostrictions are measured by means of a laser Doppler vibrometer [3]. It is understood that the measurement accuracy of magnetostriction obtained from the open type is comparable to that from the closed type with a glass plate [3] inserted between specimen and yoke. When there is no glass plate and B-coils are wound directly on specimen, the closed type gives the extremely large error. Figure 6(b) shows the comparison for the thin amorphous sheet (METGLAS 2605S-2, thickness: about 30  $\mu$ m), which is annealed at 350°C for 10 min applying magnetic field of 1.2 kA/m. In the case of silicon steel sheet, the difference between the result obtained from the open type and that from the closed type with gap is within a few percents. In the case of thin amorphous sheet, however, the difference is about several ten percents. Especially, the closed type without gap is not applicable to the magnetostriction measurements of thin amorphous sheet. It is demonstrated that the magnetostriction of amorphous metal is about ten times as large as that of silicon steel.

#### V. CONCLUSIONS

The results obtained are summarized as follows:

- (1) By exciting the main and compensating windings individually, the flux distribution can be uniform enough compared with the closed type. The maximum flux density is also sufficiently large.

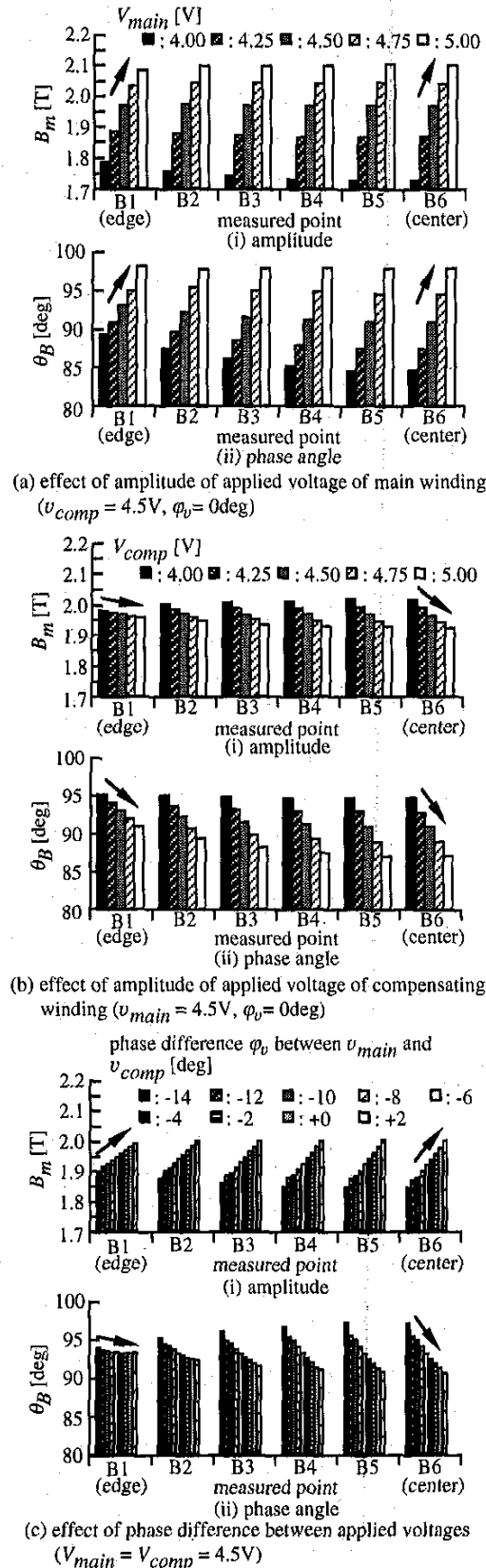


Fig. 3. Effect of applied voltages of main and compensating windings on flux distribution.

Table I. Effects of applied voltages

applied voltage			flux density	
			edge ... center	
$V_{main}$	$\nearrow$	$B_m, \theta_B$	$\nearrow \dots \nearrow$	increase
$V_{comp}$	$\nearrow$	$B_m, \theta_B$	$\searrow \dots \searrow$	decrease
$\phi_v$	(+)	$B_m$	$\nearrow \dots \nearrow$	increase
	(-)	$\theta_B$	$\searrow \dots \searrow$	decrease

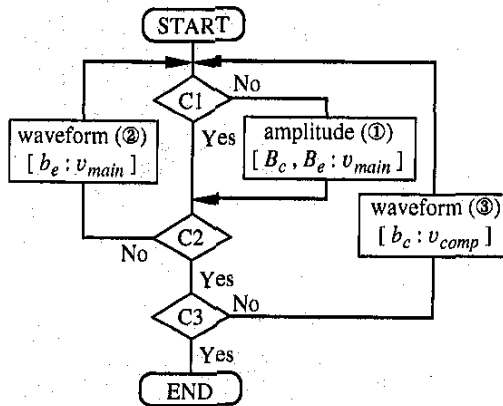
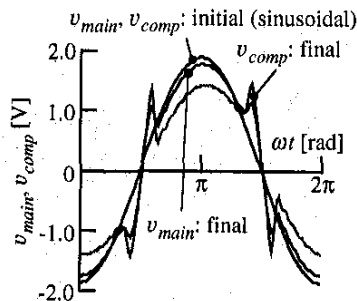


Fig. 4. Flow chart.

Table II. Convergence criteria

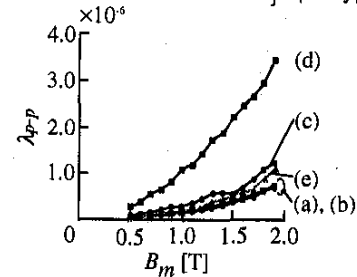
criteria	C1	C2	C3
$ \epsilon_{Bc} $ [%]	0.1	-	0.1
$ \epsilon_{Be} $ [%]	0.1	0.1	0.1
$ \epsilon_{Bc} - \epsilon_{Be} $ [%]	0.15	-	0.15
$ \Delta\theta_B $ [deg]	0.05	-	0.05
$ \epsilon_{FFc} $ [%]	-	-	0.1
$ \epsilon_{FFe} $ [%]	-	0.1	0.1

Fig. 5. Waveforms of applied voltages (JIS 27P100,  $B_m = 1.9T$ ,  $f = 50Hz$ ).

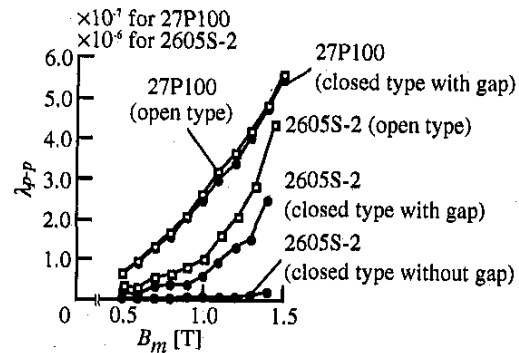
B coils, glass plate

(a)  $\circ$  : without, with  
 (b)  $\square$  : without, without  
 (c)  $\bullet$  : with, with  
 (d)  $\blacksquare$  : with, without  
 (e)  $\blacktriangle$  : with, needless

closed type  
 open type



(a) silicon steel (27P100)



(b) amorphous metal (2605S-2)

Fig. 6. Comparison of magnetostrictions ( $f = 50Hz$ ).

- (2) The proposed method of waveform control is effective.
- (3) The newly developed open type can be used for the magnetostriction measurements of thin amorphous sheet. However, the closed type is not applicable.
- (4) In the case of silicon steel sheet, the closed type is sufficient. Then, the open type is not required.
- (5) The magnetostriction of amorphous metal is about ten times as large as that of silicon steel.

## ACKNOWLEDGMENT

The authors gratefully acknowledge Emeritus Professor. T. Sasaki of Gifu University for his valuable comments on a method of excitation at an early stage of this work.

## REFERENCES

- [1] T. Yamamoto and Y. Ohya, "Single sheet tester for measuring core losses and permeabilities in a silicon steel sheet," *IEEE Trans. Magn.*, vol. MAG-10, no. 2, pp. 157-159, June 1974.
- [2] JIS, "Method of measurement of the magnetic properties of magnetic steel sheet and strip by means of a single sheet tester," C 2556-1996.
- [3] T. Nakase, M. Nakano, K. Fujiwara and N. Takahashi, "Measuring system for magnetostriction of silicon steel sheet under ac excitation using optical methods," *IEEE Trans. Magn.*, vol. 34, no. 4, pp. 2072-2074, July 1998.
- [4] T. Sasaki, S. Takada, S. Saiki and K. Hibi, "Magnetostriction measurement using interferometer in open magnetic circuits," *Nonlinear Electromagnetic Systems*, IOS Press, pp. 764-767, 1996.