Measuring method and sample size selection for the magnetostriction measurement of silicon steel

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Abstract. Magnetostriction of silicon steel is the main cause of the noise of transformer, while its measuring method is argumentative. It was investigated in this paper the effect of sample size on the measuring stability and reproducibility using laser displacement meter method. It was found that for the sample size 100mm×500mm the measuring stability and repeatability are the best comparing to the size of 30mm×300mm, 30mm×100mm and 60mm×100mm. For samples with the above for sizes cutting from the same sheet, the magnetostriction of 100mm×500mm size sample is the smallest.

Introduction

Fe-3%Si steel is widely used as the core material of transformer. Energy saving and high efficiency can be realized by decreasing the iron loss and improving the permeability of the steel. Recently, the noise pollution caused during the running of transformers has been concerned widely as the environmental conservation conscious of the public became stronger and stronger[1]. Magnetostriction during AC magnetizing of silicon steel is the main cause of noise as far as the properties of the core material is concerned. Magnetostriction has become an important quality index of silicon steel[2].

The stain gage method is widely used for the measuring of magnetostriction. In such method, stain gages are adhered closely on the sample. The stain of the sample will lead the sensitive part of the stain gage to elongate or shorten, which will cause the change of the resistance. The relationship between the change of the resistance and the stain can be represented by equation (1).

$$\Delta R/R=K.\varepsilon \quad (1)$$

In the equation, R is the original resistance of the stain gage, ΔR is the change of resistance caused by the elongation or shortening of the stain gage, K is a stain factor and$\varepsilon$is the strain.

After the stain gages are connected to a Wheastone bridge, the stain of the sample can be calculated by measuring the change of the output voltage[3]. Such method was applied mainly for measuring the magnetostriction of super-magnetostrictive material. The magnetostriction of super-magnetostrictive material is normally higher than 1000×10^{-6}, so an accurate result can be obtained by this method[4]. It is not found the related report of measuring the magnetostriction of silicon steel by such method.

The measuring of the magnetostriction of silicon steel is mainly by laser displacement meter. G.Ban[5] of the Terni institute in Italy used a laser displacement meter to measure the magnetostriction of silicon steel and found that the accuracy and the limit value can reach 0.01μm and 1.5×10^{-8} individually. M.Hirano et al. [6] of the University of Doshisha measured the magnetostriction of silicon steel by laser displacement meter and laser Doppler vibration meter respectively and found that the results met with each other.

It will be compared in this paper the measuring stability and repeatability of the strain gage method and the laser displacement meter for silicon steel. The effect of sample sizes to the measuring stability and repeatability by laser displacement meter will also be studied.

Experimental

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The silicon steel sheets were measured by a strain gage magnetostriction measuring system and a laser displacement meter magnetostriction measuring system.The calculation method of repeatability can be represented as following: repeat measuring for 10 times by the same measuring system with the sample unmoved. The repeatability S(yi) can be calculated by equation(2) if the measuring results are yi(i=1,2,3……10).

$$S(y_i)=\sqrt{\frac{\sum_{i=1}^{n}(y_i-\bar{y})^2}{n-1}} \tag{2}$$

Stability of the measuring system was evaluated difference value between the maximum and the minimum value in the case that the measuring was repeated for four times and after each time the strain gage was pasted or the sample was mounted again.

Grain orientated silicon steel sheets of 30mm×100mm were measured for 10 times by strain gage and laser displacement meter individually to compare the repeatability of the two methods. Grain orientated silicon steel sheets of 30mm×300mm were measured for 4 times by strain gage with the strain gage be removed and pasted again each time. In the other case, the sheets were measured for 4 times by laser displacement meter with the sheet being taken out and re-mounted each time. Through this way, the stability of the two methods was compared.

Grain orientated silicon steel sheet of 100mm×500mm were measured by laser displacement meter with the sample unmoved and with the sample re-mounted each time for 10 times individually. The sheet was then cut to sizes 30mm×300mm、30mm×100mm and 60mm×100mm and repeated the measuring process above for each size of sheets to study the effects of sample sizes to the measuring repeatability and stability.

Results and discussions

Comparison of repeatability and stability on the two methods. Table1 shows the saturation magnetostriction of a sheet with size 0.29mm(thickness)×30mm(width)×100mm(length) measured by strain gage and laser displacement meter method and the calculated repeatability thereof.

Table1 saturation magnetostriction measured for 10 times by strain gage and laser displacement meter method and the calculated repeatability

Measuring times	saturation magnetostriction $\lambda s(\times 10^{-6})$	
	Strain gege	laser displacement meter
1	11.1	5.470
2	10.1	5.263
3	8.509	5.302
4	9.741	5.277
5	8.452	5.410
6	8.914	5.244
7	8.719	5.252
8	9.549	5.208
9	7.863	5.174
10	8.366	5.334
repeatability	0.979	0.090

It can be seen from table1 that the repeatability of sheets with the same size measured by strain gage and laser displacement meter method for 10 times was 0.979×10^{-6} and 0.090×10^{-6} respectively. The result indicated that the repeatability of the laser displacement meter method was better than that of the strain gage method.

Table 2 shows the measuring and calculation results for the stability test by strain gage and laser displacement meter method. It can be seen from table2 that the stability of sheets with the same size

measured by strain gage and laser displacement meter method for 4 times was 1.31×10^{-6} and 0.207×10^{-6} respectively.

Table 2 the saturation magnetostrictions and the calculated stability of sheets measured by the two methods

Measuring times	saturation magnetostriction $\lambda s(\times10^{-6})$	
	Strain gege	laser displacement meter
1	11.39	4.131
2	11.98	4.215
3	11.92	4.008
4	12.70	4.082
stability	1.31	0.207

The measuring principle of strain gage method was as following: steel sheet on which strain gage was pasted was linked a the Wheastone Bridge, and then the stain could be calculated according to equation(3) by measuring the output voltage caused by the strain of the sheets.

$$e=\frac{1}{4}\cdot K\cdot\varepsilon\cdot E \qquad (3)$$

In equation (3), e is the output voltage, K is the strain gage coefficient, εis the strain of the sample and E is the input voltage.

The strain of silicon steel is very small, typically to the level of 10^{-6}. Accordingly, the output voltage is small too. The measuring system is very sensitive to the surroundings. The output voltage would changed due to electric &magnetic disturbing, noise and vibration come from the surroundings during the measurement, which will cause the worsen of repeatability and stability. On the other hand, the measuring result could also be influenced by the process of the pasting of stain gages, which will also cause the deterioration of the stability.

The measuring principle of the laser displacement meter was as following: one side of the steel sheet was fixed and the other side of the sheet to the end of a moveable bracket equipped with a reflecting mirror. Laser beam was irradiated on the reflecting mirror and then reflected to a reception prism. The strain of the sample was calculated by measuring the optical path difference using a displacement sensor. The measuring result would be less influenced by electromagnetic wave and because the strain was directly measured. The sample was settled on an antiknock table so that the influence of the vibration on the measurement can be reduced.

Repeatability and stability of samples of different sizes. Sheet of size 100mm×500mm was cut to sheets of sizes 30mm×300mm, 30mm×100mm and 60mm×100mm. The measuring results and the calculated repeatability were shown in table3.

Table3 the saturation magnetostrictions and the calculated repeatability of sheets of different sizes

Measuring times	saturation magnetostriction $\lambda s(\times10^{-6})$			
	100mm×500mm	30mm×300mm	30mm×100mm	60mm×100mm
1	1.416	3.898	5.470	5.825
2	1.401	4.288	5.263	5.414
3	1.370	4.652	5.302	6.161
4	1.384	5.484	5.277	5.943
5	1.375	5.905	5.410	5.298
6	1.370	5.971	5.244	5.044
7	1.386	6.044	5.252	4.434
8	1.412	5.806	5.208	4.688
9	1.396	5.778	5.174	4.699
10	1.377	5.710	5.334	4.457
repeatability	0.017	0.777	0.090	0.632

It can be seen from table3 that the repeatability of different sizes are quite different from each other. The repeatability of 100mm×500mm sheet is the best, while 30mm×300mm sheet is the worst.

Table4 shows the saturation magnetostriction and the calculated stability of the sheets with the 4 sizes. Each sheet was measured for 4 times by laser displacement meter with the sheet being taken out and re-mounted each time.

Table4 the saturation magnetostrictions and the calculated stability of sheets of different sizes

Measuring times	saturation magnetostriction $\lambda s(\times 10^{-6})$			
	100mm×500mm	30mm×300mm	30mm×100mm	60mm×100mm
1	1.900	4.131	9.124	6.161
2	1.850	4.215	6.458	5.151
3	1.870	4.008	5.874	4.312
4	1.817	4.082	6.131	4.238
stability	0.083	0.207	3.250	1.923

It can be seen from table4 that sample size has large influence on the stability. For 100mm×500mm sheet, the stability is 0.083×10^{-6}, while for 30mm×300mm sheet the stability is 3.250×10^{-6}.

In general, sample with large size should be taken to measure the magnetostriction because it is less influenced by shearing stress and more grains are participated in the measurement. The divergence of laser displacement meter method was calculated by measuring the elongation of the sample. The calculated measuring difference of long sample was smaller than short sample after dividing the length in the case that the divergence of laser displacement meter is the same.

Conclusions

(1) It was compared in this paper the stability and repeatability for the measurement of maganetostriction of grain orientated silicon steel by strain gage method and laser displacement meter and the results showed that the measuring stability and repeatability were better by laser displacement meter method than by strain gage method.

(2) The influence of sample size on the measuring stability and repeatability by laser displacement meter method was studied and found that the measuring stability and repeatability were better for 100mm×500mm sheet than for others.

References

[1] A. Hasenzag, B. Weiser, H. Pffitzner, Magnetostriction of 3% SiFe for 2-D magnetization patterns, Journal of Magnetism and Magnetic Materials. 160 (1996) 55-56.

[2] B. Weiser, A. Hasenzagl, T. Booth, et al., Mechanisms of noise generation of model transformer cores, Journal of Magnetism and Magnetic Materials. 160 (1996) 207-209.

[3] Shiying Ma, Qualify for the measuring repeatability and stability of measurement standard, Chinese Measurement. 1（2007）34-35.

[4] Ling Weng, Ying Sun and Shuying Li et al, Research on the design and test of rare earth super-magnetostrictive stress measurement equipment, Instrument technology and sensor. 3（2008）16-17.

[5] G. Ban, F. Janosi, Measuring system and evaluation method of DC and AC magnetostriction behavior to investigate 3.2% SiFe GO electrical steels, Journal of Magnetism and Magnetic Materials. 160 (1996) 167-170.

[6] M.Hirano, Y.Ishihara, K.Harada, et al., A study on measurement of magnetostriction of silicon steel sheet by laser displacement meter, Journal of Magnetism and Magnetic Materials. 254–255 (2003)43–46.

[7] http://www.lihua580.com/Web_jishusoft.asp?id=1,Weastone Bridge for strain measurement and principle for temperature compensation.