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Models Between Barkhausen Noise and Coercive Force of Grain-Oriented Electrical Steel

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Abstract. Effect of ball scribing on relational models between coercive force and Barkhausen noise of conventional grain-oriented (CGO) and high-permeability grain-oriented (HGO) electrical steel was investigated. Models between two parameters in both CGO and HGO electrical steel were established. The results show that after ball scribing, Barkhausen noise of CGO steel increases (26% after 4mm's scribing at 1.0T) and that of HGO electrical steel apparently decreases (17.3% with 16mm's scribing at 1.0T), while coercive force of both CGO and HGO electrical steel decreases. Models between coercive force and magnetic Barkhausen noise after scribing were also constructed according to experimental data, and the experimental data curves were analyzed in the magnetizing process, which provides reference for correlation of different magnetic parameters.

Keywords: Model, Ball Scribing, Barkhausen Noise, Coercive Force.

INTRODUCTION

Grain-oriented electrical steel is in widespread use as significant materials in various electromagnetic switches, transformers, and amplifiers[1-3]. Due to its advantages such as saving energy, significantly reducing the quality and volume, grain-oriented electrical steel is vital material for large transformers and generators, which makes it also appropriate for large-scale nuclear power plants, hydropower and thermal power plants[4-8].

Barkhausen noise and coercive force are two important parameters of electrical steel. Barkhausen noise has been extensively used as a potential tool for nondestructive evaluation of many microstructural, metallurgical, and mechanical parameters of various materials, which is widely used in automobile, aerospace industry and metallurgy apparatus[9-10]. Due to its commercial applications much research work has been targeted towards studying the effect of influencing factors on the Barkhausen noise[11-12]. One basic performance requirement of electrical steel is quickly its responding to changes in an external magnetic field, which requires low coercive force in the steel[13-15]. The lower the coercive force is, the more sensitive response the steel shows at a low magnetic field[16].

To optimize magnetic properties and solve the problem of recoating, European Electrical Steels developed a ball scribing technique[17]. Scribing the ball over the surface produces a line of damage able to act as an artificial grain boundary, which would change related magnetic properties of electrical steel. Effect of ball scribing on the relational between Barkhausen noise and coercive force of grain-oriented electrical steel was investigated in this paper [18-19].

EXPERIMENTAL MATERIALS AND METHOD

Tested samples were composed of conventional and high-permeability grain-oriented electrical steel sheets. Two types of electrical steel were named C711 and H668 respectively, whose chemical composition is shown in TABLE1.

TABLE (1). Chemical Composition of C711 and H668 Tested Materials

	Si	C	Mn	S	Cu	P	Al
C711	3.05	0.032	0.065	0.020	0.028	0.012	0.008
H668	3.09	0.054	0.072	0.018	0.075	0.015	0.010

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The samples are all standard Epstein sample with size of 350mm×30mm×0.3mm. Initial magnetic properties of C711 and H668 are shown inTABLE2. Ball scribing was achieved by self-designed ball scribing instrument, with which scribing spacing of 2mm, 4mm, 8mm and 16mm was made.

TABLE (2). Initial Magnetic Properties of C711 and H668 at 1.0T

	Iron Loss (W/Kg)	Coercive Force (A/m)	Permeability	Barkhausen Noise(mV)
C711	0.711	282.9	799.4	0.391
H668	0.668	287.6	2473.7	0.447

The MBNrms and coercive force measuring system comprises of the magnetization system and a signal detection unit[20]. Magnetic measurements were finished in an Epstein frame, and a feedback control system implemented in LabVIEW was used to control the flux density and to make the induced secondary voltage waveforms sinusoidal to have repeatable and comparable measurements. The computer monitor was remote from the measuring system to avoid interference with the measurements. Coaxial cables were used for all connection leads. Each strip was magnetised under sinusoidal flux density, from 8.0 mT to 1.5 T at a magnetizing frequency of 50 Hz. Each measurement of MBNrms was made three times and then averaged. Before each measurement the tested sample was drawn out and demagnetized.

RESULTS AND DISCUSSION

Correlation Modeling before Scribing

As shown in FIGURE1(a), Barkhausen noise of CGO is higher than that of HGO before ball scribing, at peak flux density of 1.0T, MBNrms of C711 and H668 is 0.391mV and 0.447mV respectively. At the very starting growth of flux density there is not much difference between Barkhausen noise of CGO and HGO. As shown in FIGURE1(b), coercive force of CGO and HGO electrical steel does not vary much. As the peak flux densities increase, their coercive force rises alternatively.

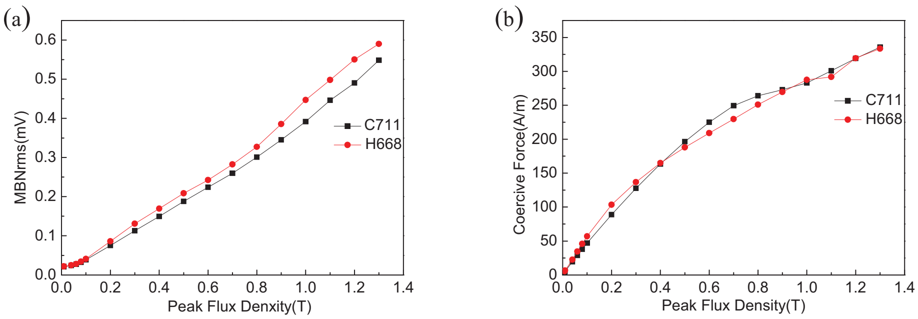

FIGURE 1. Comparison of Magnetic Barkhausen Noise(a) and Coercive Force(b) at Different Peak Flux Densities

Relational modeling between Barkhausen noise and coercive force were constructed according to the figure shown as in FIGURE2. At the very beginning region, two types of steel show a similar variation trend, such variation trend occurs at rather low flux densities, which may be attributed to experimental error or instrument sensitivity. For calculation simplicity, the cure was fit linearly into two sections at high and low flux densities, and ideal simulation results were achieved, which indicates separation of correlation into two parts is feasible and reasonable.

For CGO electrical steel, modeling of the first and second linear zones is as follows,

$$\begin{cases} y = 0.00104x - 0.01548 \quad (0.1T\sim 0.7T) \\ y = 0.00336x - 0.5732 \quad (0.7T\sim 1.3T) \end{cases} \tag{1}$$

where, y and x represents MBNrms and coercive force respectively, the fitting degree is 0.994 and 0.989.

For HGO electrical steel, modeling of the first and second linear zones is as follows,

$$\begin{cases} y = 0.00134x - 0.0449 \quad (0.1T\sim0.7T) \\ y = 0.00311x - 0.43999 \quad (0.7T\sim1.4T) \end{cases} \tag{2}$$

where, the fitting degree is 0.987 and 0.988 respectively.

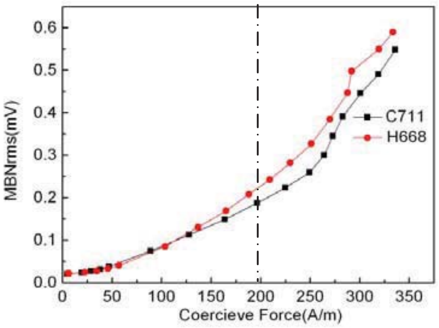

FIGURE 2. Relational Modeling between Magnetic Barkhausen Noise and Coercive Force of Electrical Steel before Scribing

Variation Trend of Barkhausen Noise and Coercive Force after Scribing

Variation of the Barkhausen noise of C711 with and without ball scribing is shown in FIGURE3(a). It is clear that Barkhausen noise increases after ball scribing. Barkhausen noise of CGO electrical steel after 2mm's scribing is the highest, and 4mm comes second, and 16mm's scribing is lower in Barkhausen noise, and 8mm's scribing is lowest. Variation trend of Barkhausen noise at high flux densities after different scribing space is consistent with that at low flux densities, and there is not much difference with scribing spacing of 8mm and 16mm. Barkhausen noise of H668 with and without ball scribing is compared in FIGURE3(b). After ball scribing there is a marked decline in Barkhausen noise. Variation trend of Barkhausen noise at low peak flux densities is also different from that at high flux densities, and at the very starting section growth of flux density there is not much difference among samples before and after scribing. Such contradiction suggests that the MBNrms changing process is complex and the results may be associated with materials having different densities of pinning sites, precipitates and grain boundaries possibly higher in smaller grain material.

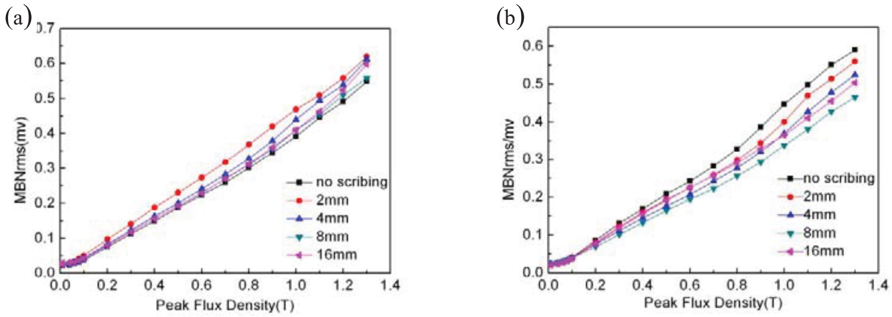

FIGURE 3. Relational Modeling between Magnetic Barkhausen Noise of C711(a) and H668(b) Electrical Steel after Scribing of Different Spacing

As shown in FIGURE4(a), coercive force of C711 with and without ball scribing is compared. It is obvious that after scribing coercive force falls, and scribing of 2mm, 4mm and 16mm shows similar growing trend while scribing of 8mm shows lowest coercive force. Variation trend of coercive force of H668 before and after ball scribing is shown in FIGURE4(b). After scribing the coercive force of H668 apparently decreases. Coercive force after scribing of 2mm, 4mm and 8mm is almost the same and that of 16mm is higher.

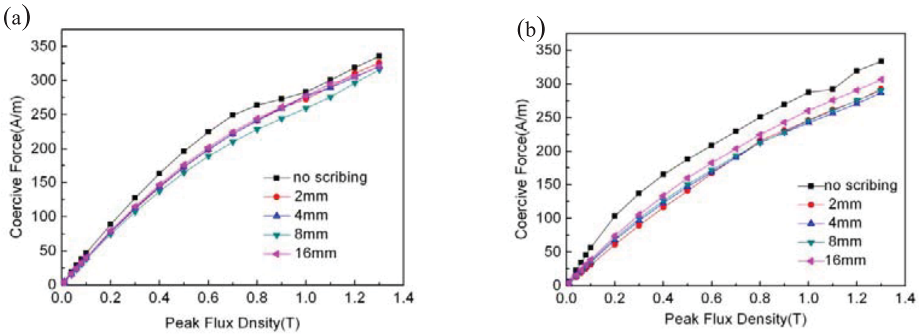

FIGURE 4. Relational Modeling between Magnetic Coercive Force of C711(a) and H668(b) Electrical Steel after Scribing of Different Spacing

As the variation trend of MBNrms and coercive force is quite different between CGO and HGO steel shown and analyzed above, we could deduce that after scribing the relations between Barkhausen noise and coercive force would change. The increase and decrease of Barkhausen noise after ball scribing would certainly change the correlation modeling of CGO and HGO electrical steel.

Correlation Modeling after Scribing

As shown in FIGURE5, the curve could be divided into two linear sections. Therefore, the correlation models of both CGO and HGO electrical steel were constructed below,

$$\begin{cases} y = 0.0013x - 0.01153 \quad (ZONE1) \\ y = 0.00308x - 0.39255 \ (ZONE2) \end{cases} \tag{3}$$

Where, y and x represent MBNrms and coercive force respectively, the fitting degree is 0.998 and 0.997 respectively.

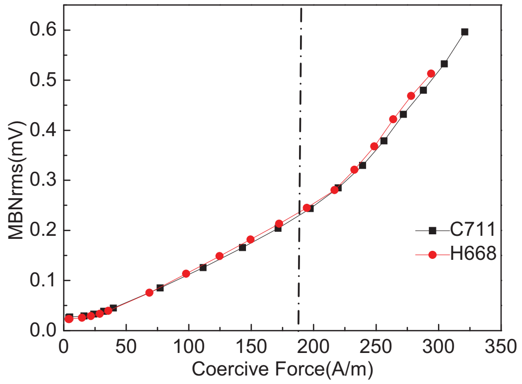

FIGURE 5. Relational Modeling between Magnetic Barkhausen Noise and Coercive Force of Electrical Steel with Average Spacing'S Scribing

The fitting degree above indicates separation of correlation into two parts is quite feasible and reasonable. The main marked change from FIGURE2 is that the two curves of CGO and HGO coincides well and variation trend is almost the same. Such change could be attributed to different variation trend of Barkhausen noise after scribing analyzed above.

CONCLUSIONS

(1) Correlation models between magnetic Barkhausen noise and coercive force of both CGO and HGO electrical steel were constructed respectively in two separate sections, and the fitting degree is quite high.

(2) Barkhausen noise variation after ball scribing was analyzed. The MBNrms increases in CGO electrical steel, while in HGO steel it decreases. For both CGO and HGO electrical steel, scribing spacing of 8mm achieves lowest Barkhausen noise.

(3) For both CGO and HGO electrical steel, coercive force apparently falls after scribing. Coercive force after scribing of 2mm, 4mm and 8mm is almost the same and that of 16mm is higher.

(4) Correlation models between coercive force and Barkhausen noise were constructed after scribing, and the results show that there is no marked difference in the model for two types of steel after scribing, which also coincides well with the curves obtained from the experimental data. Such variations from correlation models may be contributed to materials having different densities of pinning sites, precipitates and grain boundaries.

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