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Investigation of the Effects of Strips Thickness and Grain Size on AC Magnetic Barkhausen Noise of Grain-oriented Electrical Steel

***Abstract**. The influence of sample thickness and grain size of Conventional Grain-Oriented (CGO) and High Permeability Grain-oriented (HGO) steels on Magnetic Barkhausen Noise (MBN) of Epstein strips has been examined. It might be expected that MBN decreases with increasing sample thickness due to eddy current damping but the measurements show that the average domain width, hence the grain size influences MBN in strips less than 0.35 mm thick. From 0.35 mm and above, both strip thickness and domain width influence MBN in CGO and HGO.*

***Streszczenie.** Zbadano wpływ grubości próbki i rozmiaru ziarna dla stali konwencjonalnej o ziarnie zorientowanym (CGO) i stali o wysokiej przenikalności i ziarnie zorientowaym (HGO) na paskach Epsteina. Można oczekiwać, że amplituda sygnału Barkhausena MBN zmniejsza się wraz ze wzrostem grubości próbki z uwagi na efekt tłumienia od prądów wirowych, lecz pomiary wykazały, że średnia szerokość domen, związana z rozmiarem ziarna, ma wpływ na MBN w paskach o grubości mniejszej niż 0,35 mm. Dla grubości 0,35 mm i powyżej, grubość paska i szerokość ziarna mają wpływ na MBN zarówno dla stali CGO i HGO. (**Badania wpływu grubości próbki i rozmiaru ziarna na efekt Barkhausena w blachach zorientowanych**)*

Keywords: Magnetic Barkhausen noise, Grain-oriented electrical steel, Eddy current.
Słowa kluczowe: Magnetyczny efekt Barkhausena, stal o ziarnie zorientowanym, prądy wirowe.

Introduction

The Magnetic Barkhausen Noise (MBN) was first observed by Professor Barkhausen in 1917 [1]. He found that the magnetisation change as a function of the applied magnetic field is not smooth but increases in steps. These steps were noticed as clicks in a telephone receiver. MBN originates from the discontinuous movement of domain walls (DWs) during magnetization of a ferromagnetic material when the DWs overcome pinning sites such as dislocations and grain boundaries which act as obstacles to their movement. The response depends on the density and nature of pinning sites (defects) within the material. These may be oxides, carbides, pores, voids, cracks, grain boundaries or other mechanical inhomogeneities.

Domain wall motion contributes more to MBN than domain rotation. This can be understood by just looking at the nature of the effects. If a domain wall moves, it travels a greater distance within the material than a domain wall which ‘bows’ with its end fixed thus generating a greater rate of change of magnetisation which results in more MBN amplitude. When considering a B-H loop, most Barkhausen activities take place in the area around the coercive field where the rate of change of magnetisation is highest [2, 3]. It is known that MBN depends on the microstructure of the material which causes changes in its shape and amplitude. It is also stress dependent. This fact makes the examination of MBN an important method for investigating properties of magnetic materials such as grain size, heat treatment, strain, and mechanical properties such as hardness [4].

This noise phenomenon is investigated statistically through the detection of the random voltage observed on a search coil during the magnetisation of the material [5]. There are two types of MBN detection viz: surface and encircling. For surface type technique, the search coil (pick-up coil) is placed on the surface of the specimen while in the encircling type, the search coil is wrapped around the specimen.

Grain-oriented electrical steel is a soft magnetic material and usually has a silicon level of 3%. It is produced in such a way that the best properties are developed in the rolling direction, due to a tight control of the crystal orientation relative to the sheet. This special orientation increases the magnetic flux density in the coil rolling direction. It is utilised in the cores of high-efficiency transformers, electric motors and generators. Grain-oriented electrical steel is comprised of the conventional grain-oriented (CGO) and high permeability grain-oriented (HGO) steels.

The grain size of HGO is on the average higher than that of CGO. Grain orientation determines the static magnetic domain configuration [6]. The domain wall spacing is wide in grains oriented near (110) [001], and narrower in grains having [001] directions out of the sheet plane. As a rule, the grain-grain misorientation in (110)[001] oriented silicon steel increases as the grain size decreases, larger grain boundary micro demagnetizing fields would be expected in small grain materials [6]. This was corroborated by the findings in [7] where it was stated that the average deviations of the <100> axis from the rolling direction in HGO and CGO strips are about 3° and 7° respectively. Grain-oriented electrical steel is without doubt the most important soft magnetic material in use today. The magnetization process in electrical steel is influenced by impurities, grain orientation, grain size, strain, strip thickness, and surface smoothness. One of the most important ways to improve soft magnetic materials is to remove impurities, which impedes domain-wall movement.

It is reported that the root mean square (RMS) of MBN decreased with increasing thickness in S235JGR2 steel with ferrite-pearlite structure [8] and non grain-oriented steel [9]. In this investigation, MBN measurements were carried out on different thicknesses of strips of CGO and HGO to determine the influence of strip thickness and grain size on MBN of these materials.

Experimental Details

MBN measurements were made using an established system [10]. The block diagram is shown in figure 1. The voltage waveform to control the applied flux density was generated through a digital output card and sent to the magnetic circuit through an impedance transformer. The magnetising current was fed to a magnetising yoke which houses the sample through a shunt resistor. The primary coil has 100 turns. When the sample is magnetised, the domain walls move. The movement occurs in series of sudden jumps leading to MBN which is detected as induced voltage in the 500-turns search coil wrapped around the sample. The MBN signals were analysed using the National Instruments software package ‘LabVIEW’. The induced voltage was filtered to remove the dominant Faraday emfs. A digital band pass filter was used so that signals in the range 25 KHz - 75 KHz were detected at magnetising frequency of 50 Hz. The system uses one search coil (secondary coil) arrangement rather than the double search coil arrangement where some Barkhausen events are lost in the subtraction process [11]. Background noise interference is always a challenge in measuring MBN especially at very low flux densities. The low noise NI4461 card with 24 bit resolution and a sampling rate of 204.8 KHz and 92 KHz bandwidth was chosen to take the measurements to minimize the influence of thermal noise. The card sits in a PXI platform with specially prepared and tested chassis; hence works in a predictable environment which means the measurements are more reliable and repeatable. In order to reduce environmental noise, the yokes, the sample and the search coil carrier were placed in a noise shielding chamber. The computer monitor was remote from the measuring system to avoid its radiation having interference with the measurements. All connection leads were coaxial cables. With this measurement system, a background noise level which is about 100 times lower than MBN level was achieved.

The MBN signal was analysed using the RMS which was calculated over 20 consecutive cycles. RMS was chosen to analyse the signal because its value is fairly stable from cycle to cycle. The RMS value is also very useful for determining amplitude as a function of time particularly for cyclic phenomena such as MBN which has both positive and negative amplitudes per cycle [12]. It also allows better comparison with the work of other investigators that have also measured RMS of MBN. However, similar conclusions are expected to be drawn if the MBN signal were to be analysed in terms of other parameters such as total sum of amplitudes, total number of peaks etc. The uncertainty of the measurement was 15% at flux densities below 0.2 T and 7% at flux densities of 0.2 T and above.

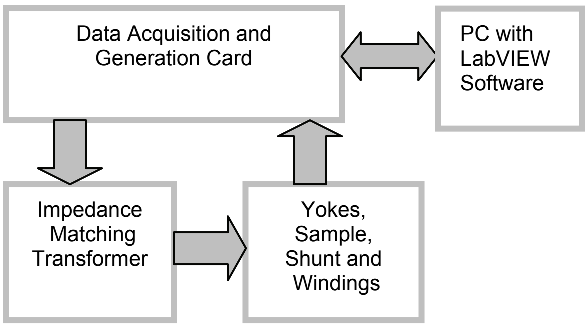

Fig.1. Block diagram of the MBN measurement system.

Results and Discussion

MBN measurements were made on 3 strips each of CGO of thicknesses 0.23 mm, 0.27 mm, 0.30 mm, 0.35 mm and 0.50 mm and HGO 0.27 mm and 0.30 mm in the peak flux density (B) range of 8 mT to 1.2 T. HGO strips are normally manufactured with thicknesses of 0.27 mm and 0.30 mm. The average grain sizes are 4.0 mm and 9.0 mm for CGO and HGO respectively. The average static magnetic domain width of all the samples was calculated from observations made using the Bitter technique [13]. They are 0.45 mm, 0.48 mm, 0.49 mm, 0.52 mm and 0.60 mm for the sample thicknesses of 0.23 mm, 0.27 mm, 0.30 mm, 0.35 and 0.50 mm respectively for the CGO samples; 0.64 mm and 0.68 mm for the 0.27 mm and 0.30 mm thick HGO samples respectively. The size and the distribution of the precipitates were almost the same for the respective samples. Therefore the primary reason for the differences in MBN could be attributed to grain size and thickness effects. In grain oriented electrical steel, pinning sites are preferentially located at grain boundaries which act as obstacles to the movement of domain walls [14] hence it is reasonable to expect some relationship between grain size and Barkhausen noise [15].

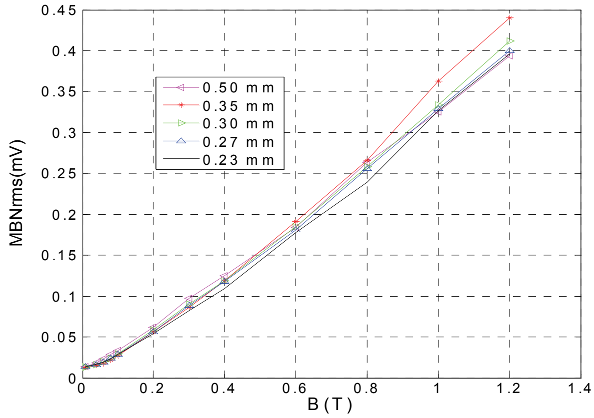

Fig. 2:Variation of average MBN with B in CGO of different thicknesses.

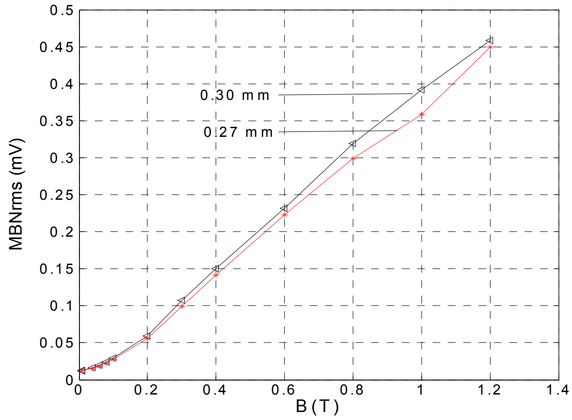

Fig. 3:Variation of average MBN with B in HGO of different thicknesses.

Figures 2 and 3 show the variation of average MBNrms of the 3 strips each of CGO and HGO of different thicknesses with B. It is observed that average MBN increases with B in all the test samples. The percentage increase in average MBN in CGO between samples of thicknesses from 0.23 mm to 0.30 mm is shown in table 1. In HGO, MBN increased by an average of 6% above 0.2 T and 5% from 0.2 T and below between samples of thicknesses 0.27 mm and 0.30 mm. In all tested materials, it is interesting to observe that the average MBN increases with the average domain width and thickness for samples with thicknesses less than 0.35 mm. For CGO, this is illustrated in figure 4. The eddy current damping which increases with increasing strips thickness and retards the movement of domain wall thereby reducing the MBN has no effect here. This is because in silicon iron sheet of standard thickness, typically 0.33 mm and below, at 50 Hz magnetisation, the 'skin effect' is negligible [16], that is the flux may be taken as being uniformly distributed through the sheet thickness. Increased domain width leads to higher MBN because domain walls will move further between pinning sites thereby generating larger changes in magnetisation which results in larger MBN [14, 17 and 18]. MBN amplitude is higher in HGO than CGO as can be observed from figures 3 and 4 which are consistent with earlier works [10, 19]. This is also due to the higher grain size and hence domain width of HGO. Grain sizes affect the magnetic properties by the generation of closure domains at the grain boundaries due to the presence of 'free poles' which occur as a result of the change in crystallographic direction across the grain boundary and eventually disappear in the fully magnetised state [20].

The variation of average MBN of 0.35 mm and 0.50 mm thick CGO samples with B is shown in figure 5. MBN decreased by an average of 6% from 0.6 T to 1.2 T with increased sample thickness and increased by an average of 14% below 0.6 T with decreased sample thickness. This shows that both the domain width and the sample thickness influenced the MBN. The 0.50 mm thick sample, although having higher domain width (0.60 mm) has lower MBN from 0.6 T and above. This is because of eddy current damping which increases with thickness and is always higher at high flux densities. Also, although it has domain width of 0.52 mm, the 0.35 mm thick sample has higher MBN below 0.6 T. This indicates that the influence of domain width predominates in the regime.

Table1: Percentage increase in average MBN between CGO samples of thicknesses less than 0.35 mm

Flux density (T)	Above 0.2 T	0.2 T and below
Test strips as specified below	% increase in average MBN	
0.23 mm and 0.27 mm thick	4.5	0.4
0.27 mm and 0.30 mm thick	2.0	1.5
0.23 mm and 0.30 mm thick	6.0	2.0

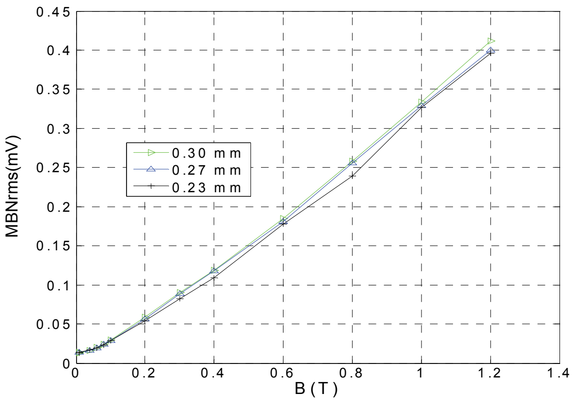

Fig. 4: Variation of average MBN of CGO of thicknesses less than 0.35 mm with B.

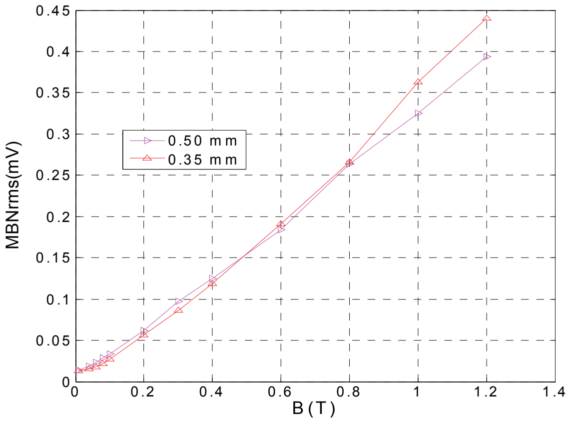

Fig. 5:Variation of average MBN of CGO of thicknesses of 0.35 mm and 0.50.

The average distance moved by domain walls motion was calculated for all the samples under test at the measured peak flux densities from which the average velocity of domain walls motion was found. Figures 6 and 7 show the variation of average velocity of domain wall movement with peak flux density in CGO and HGO respectively. It is observed that the average wall velocity increases with peak flux density at all the flux densities measured as expected. When the MBN were plotted against the average domain wall velocity of both CGO and HGO as shown in figures 8 and 9 respectively, significant correlation was found to exist between them at all the peak flux densities measured.

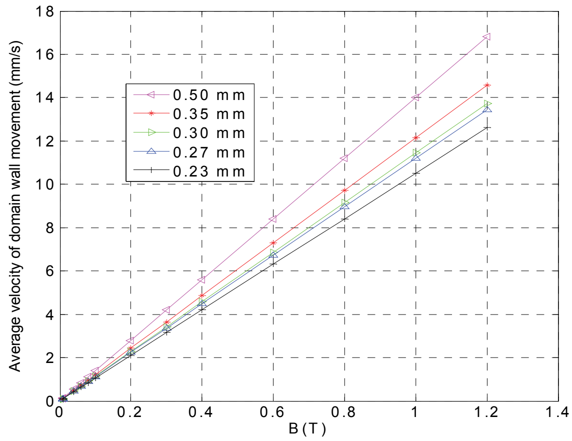

Fig. 6:Variation of average domain wall velocity with peak flux density in CGO.

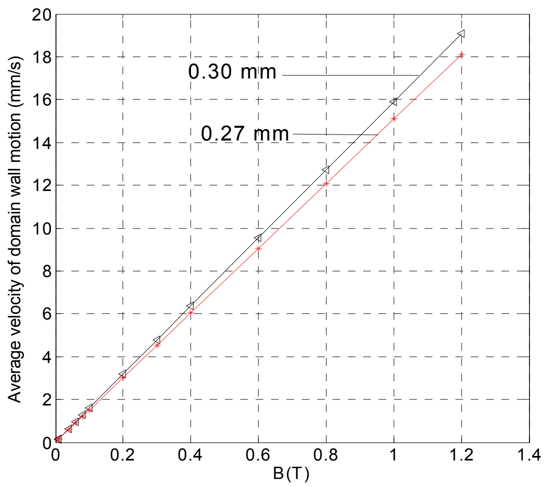

Fig.7:Variation of average domain wall velocity with peak flux density in HGO.

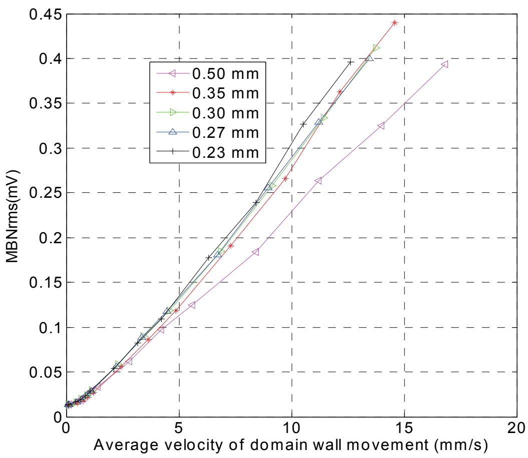

Fig 8:Variation of average MBN with average domain wall velocity at the measured peak flux densities in CGO.

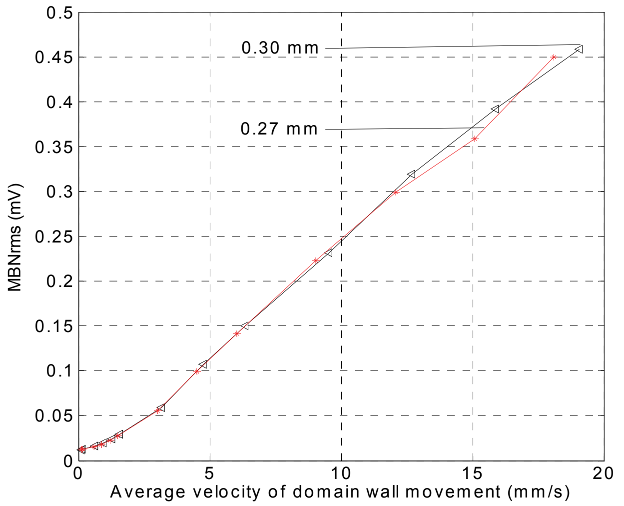

Fig. 9:Variation of average MBN with wall average velocity at the measured peak flux densities in HGO.

Conclusion

MBN in grain-oriented electrical steel is affected by both average domain width and thickness for strips 0.35 mm thick and above. It increases with increasing domain width and decreases with increasing sample thickness owing to eddy current damping effects. Domain width, hence grain size is the only influence on MBN for strip thicknesses below 0.35 mm, given the same microstructure. Significant correlation was found between average domain wall velocity and MBN at all the peak flux densities measured.

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