Journal of ELECTRICAL ENGINEERING, VOL 61. NO 7/s, 2010, 69-72

BARKHAUSEN NOISE IN GRAIN-ORIENTED 3% Si-Fe AT 50 HZ

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Barkhausen noise (BN) measurements were performed on samples of high permeability and conventional grain-oriented steels at both high and low flux densities in order to investigate the characteristics in each magnetization regimes. Previous works deal with measurements of Barkhausen noise carried out at high flux densities (0.2 T and above) but this work demonstrates that Barkhausen noise has different characteristics at low flux densities (8 mT to 0.2 T). The results show that the amplitude sum and the RMS Barkhausen signals are higher for High Permeability Grain-Oriented (HGO) steel than Conventional Grain-Oriented (CGO) steel at high flux densities because the grain size of HGO is higher than that of CGO. Domain wall spacing increases with increasing grain size. Hence increased grain size means domain walls move further between pinning sites resulting in larger BN signal**.** Below 0.2 T, the BN signal becomes higher for CGO steel. HGO samples were mechanically scribed on one surface transverse to the rolling direction. It was observed that scribing reduced the BN amplitude at high flux densities. This is due to the decrease of domain width by scribing**.** Then the trend reverses again at low flux density.

Keywords: Barkhausen noise, grain-oriented steel, amplitude sum analysis, RMS analysis, grain size

1 INTRODUCTION

Barkhausen Noise (BN) is produced by discontinuous changes in the magnetization (M) of ferromagnetic materials subjected to a changing magnetic field (H). The discontinuous changes are attributed to variations in the speed of the magnetic domain walls when these domains interact with pinning sites formed by local micro structural defects such as dislocations, precipitates, inclusions and grain boundaries. The pinning site interaction impedes domain wall motion until sufficient external energy is supplied to overcome local energy barriers created by the pinning sites. When this condition is reached, sudden changes in M are produced by the abrupt movement of domain walls. This phenomenon can be macroscopically observed as a voltage pulse, denoted as BN, which is induced in a search coil placed around the specimen [1]. In this work, Barkhausen noise measurement was carried out on strips of HGO steels and CGO steels from each of two producers at sinusoidal peak flux density in the range 8 mT to 1.5 T at 50 Hz. BN studies aimed at non-destructive testing applications are usually carried out under quasi-static or very low frequency magnetization conditions but 50 Hz has been chosen because it is believed that at this frequency the BN signal is possibly more related to dynamic hysteresis processes and can give more information about ac magnetization processes which low frequency BN measurements cannot.

Grain orientation determines the static magnetic domain configuration [2]. The 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[2]. This was corroborated by the findings in [3] 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 boundaries are obstacles to domain wall movement. Moreover, pinning sites such as precipitates, dislocations and inclusions are preferentially located at grain boundaries. It is reasonable therefore to expect some relationship between grain size and Barkhausen emission [4].

In reference [5], the domain width was reported to be proportional to the square root of grain size for grain diameters between 0.05 and 10 mm. Hence, both the number of domain walls and the number of pinning sites per unit volume is greatest for small grains. This finding was substantiated in reference [6] where it was shown that the number of Barkhausen noise pulses varies inversely with grain size. The domain structure can be separated into two components *viz* a main domain structure formed by large bar domains, and a supplementary closure domain structure. The magnetization process takes place by rearrangements of the main domain structure with small change in the flux closure domains. Domain structure differs from grain to grain therefore the area of investigation must include a large number of grains.

2 EXPERIMENTAL DETAILS

A block diagram of the Barkhausen noise measuring system incorporating the flux density waveform control is shown in Fig. 1. The waveform to control the flux density, was generated through a digital output card, NI4461. This waveform was fed through an impedance matching transformer to maximize power transfer between the signal source and magnetizing current circuit. The system uses a closed circuit magnetizing yoke. The primary (100 turns) and secondary (500 turns) were wound on a plastic former housing the sample. The primary coil was wound over the secondary winding. The system uses one search coil (secondary coil) arrangement rather than the double search coil arrangement where some Barkhausen events

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ISSN 1335-3632 © 2010 FEI STU

are lost in the subtraction process [7]. The BN signals were analyzed using the National Instruments software package 'LabVIEW'. The secondary voltage was filtered to remove the dominant Faraday emfs. A band pass filter was used so that signals in the range 25 KHz to 75 KHz were detected at magnetizing frequency of 50 Hz [8]. The measured primary current and secondary voltage signals were processed by means of the data generation and acquisition card (NI4461). This low noise card with 24 bit resolution and a sampling rate of 204.8 KHz and 92 KHz bandwidth was chosen to minimize the influence of thermal noise. 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 interference with the measurements. The acquired data was analyzed using the root mean square and total sum of amplitudes. The uncertainty of the measurement was 15% at low flux densities and 7% at high flux densities.

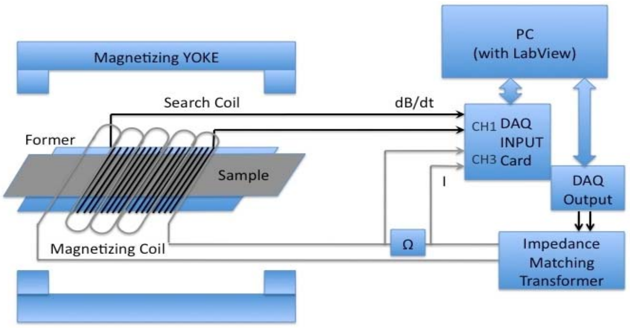

Fig.1. Barkhausen noise measuring system

3 EXPERIMENTAL RESULTS AND DISCUSSION

BN measurements were made on forty strips from producer P1 comprising 20 CGO and 20 HGO 300 mm x 30 mm x 0.27 mm in size. Another 40 strips from producer P2 comprising 20 CGO and 20 HGO strips were also tested. The CGO and HGO strips had average grain sizes of 4 mm and 9 mm respectively. Figure 2 shows typical BN signals and background noise of the experimental setup.

Figure 3 shows a typical Barkhausen noise spectra obtained from a sample of HGO magnetized at 50 Hz, 1.0 T. The sinusoidal curve is the flux density waveform at a 1000 times smaller scale. One cycle of magnetization is shown. As expected, the BN is highest at points in time corresponding to when the material was experiencing maximum rate of change of magnetization at the coercive field [9].

Figures 4 and 5 show the variation of BN, rms (average for each of 20 strips) of CGO and HGO with peak flux density from producers P1 and P2 respectively . RMS BN response is around 20% higher in HGO than CGO above 0.2 T for samples from P1. However at lower flux densities, the trend reverses and the BN, rms of the HGO is around 11% lower than that of CGO. The BN, rms of HGO from P2 is about 5% higher than that of CGO above 0.2 T and 8% smaller at low flux densities. This trend was consistently obtained for the forty strips each of CGO and HGO tested.

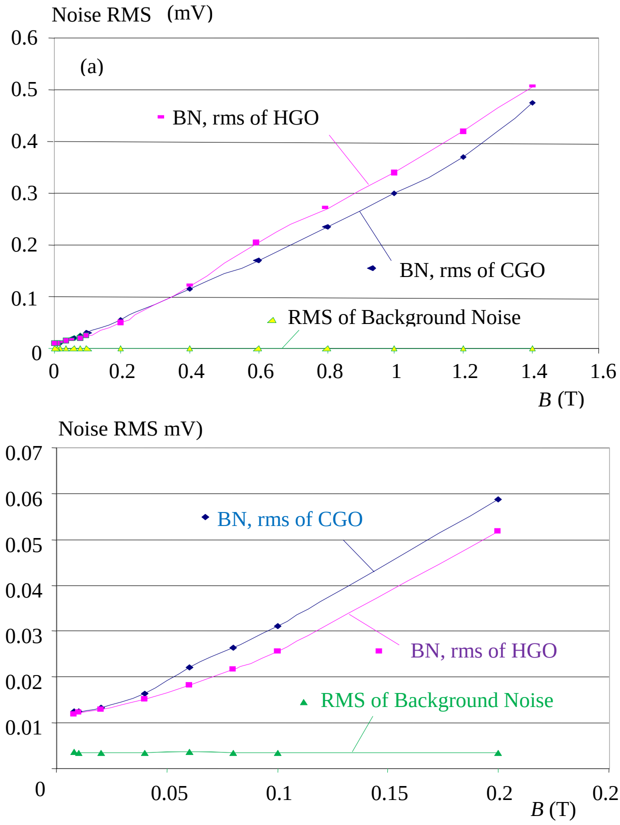

Fig. 2. Comparison: (a) – of BN, rms of strips at different flux densities with background noise of experimental set-up, (b) - in the low field regime

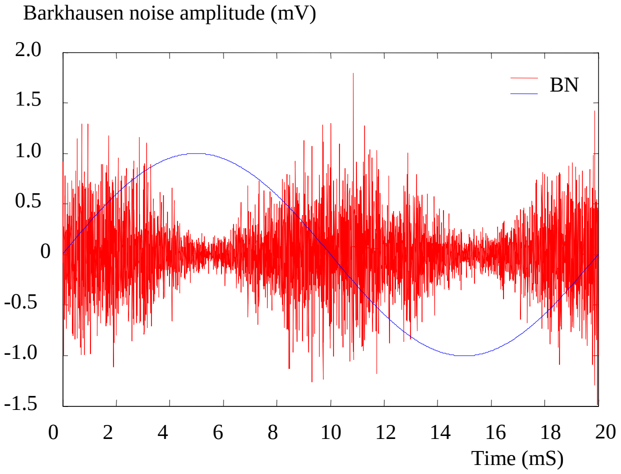

Fig. 3. BN spectrum of a strip of HGO magnetized at 50 Hz, 1.0 T

The variation of the average Total Sum of BN Amplitude of 20 strips each of HGO and CGO from producers P1 and P2 with flux density were also obtained. The Total sum of BN Amplitude of HGO is about 17% higher than that of CGO from P1 above 0.2T and 9% smaller at lower flux densities. From P2, the total sum of BN Amplitude of HGO is about 4% higher than that of CGO above 0.2T and 7% smaller at lower flux densities. This trend was also consistently obtained for the 40 strips each of CGO and HGO tested.

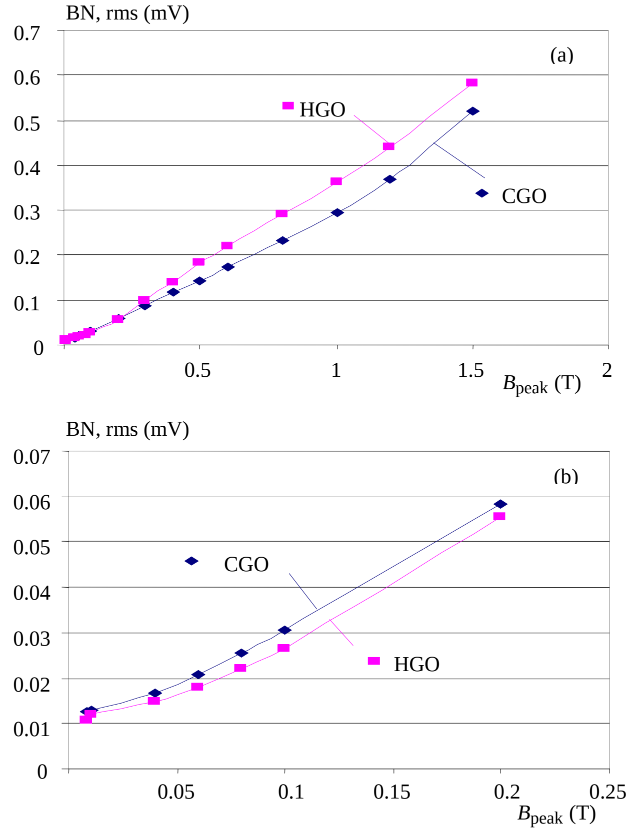

Fig. 4. (a) -Variation of average BN, rms of 20 strips each of CGO and HGO from P1 with peak flux density. (b) - the same comparison in the low field regime

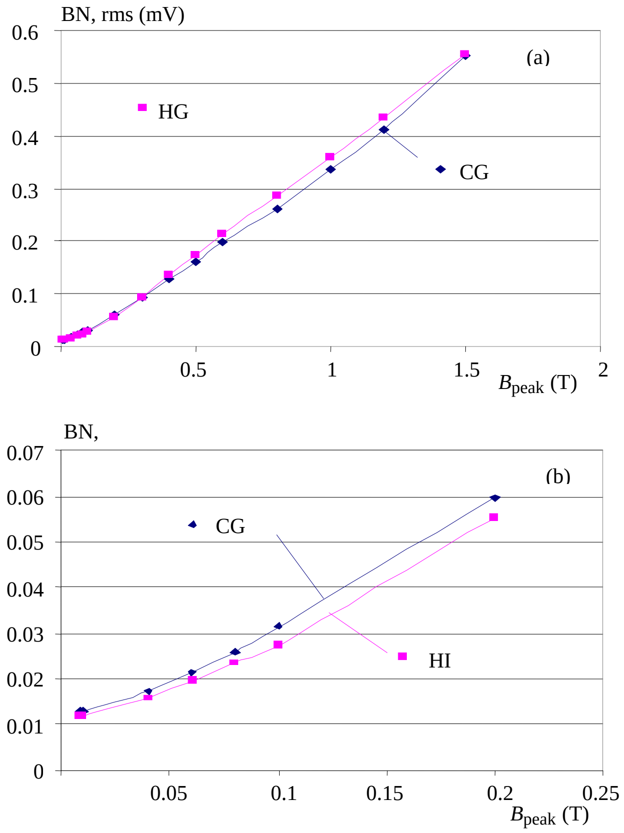

Fig. 5. (a) - Variation of average BN, rms of 20 strips each of CGO and HGO from P2 with peak flux density, (b) - Comparison in the low field regime

The observed higher BN response of HGO over CGO at higher flux densities (above 0.2 T) in this work is because the grain size of HGO is much higher than that of CGO. The domain width in 3% Si-Fe increased with increasing grain size. Increased grain size allows domain walls to move further between pinning sites and thereby generate larger changes in magnetization which results in a larger BN signal amplitude [6, 10, 11]. Another reason for the observed higher BN response of HGO is because grain-grain misorientation is higher in CGO which results in strong depression of the BN level which can be attributed to a decrease in the instantaneous rate of change of the magnetic flux during Barkhausen jumps, due to increased demagnetizing effects. The grain-grain misorientation in (110)[001] oriented silicon steel increases as the grain size decreases, thus larger grain boundary micro demagnetizing fields would be expected in small grained materials.

At low fields, domain wall motion has an intermittent, jerky character, with sparse Barkhausen jumps. The implication of this is that smaller grain samples (CGO) which have more grain boundaries acting as pinning sites and hence large fractional volume than HGO will have a greater number of these sparse Barkhausen jumps which will sum up to higher Barkhausen noise amplitude. This explains why, at low flux density, the BN amplitude is higher in CGO material.

After initial testing, one surface of ten HGO samples was mechanically scribed at 5 mm intervals transverse to the rolling direction. Scribing introduces local strain which decreases domain wall spacing thereby limiting the mean free path of domain walls. The variation of average BN, rms of ten strips each of CGO, HGO and domain scribed strips with peak flux density is shown in Fig. 6. It was observed that scribing reduced the BN amplitude by about 5% at high flux densities. This is due to scribing breaking the spatial correlation between jumps [12]. The trend reverses at low flux densities.

4 CONCLUSION

BN in grain-oriented electrical steel at power frequency has different characteristics at high and low flux density due to grain size/misorientation effects. The larger BN signal of HGO compared to CGO at high flux densities occurs because the grain size of HGO is on average higher than that of CGO. Domain wall spacing increases with increasing grain size. Increased grain size enables domain walls to move further between pinning sites and so generate larger changes in magnetization which results in larger BN signal. In addition, grain to grain misorientation, which is higher in CGO than HGO, results in a strong suppression of the BN level.

At low fields domain walls exhibit a jerky motion consisting of random sequence of Barkhausen jumps whose cumulative effect will be higher in amplitude for CGO steels because of increase in the number of grain boundaries and grain boundary area acting as pinning sites since their fractional volume is larger.

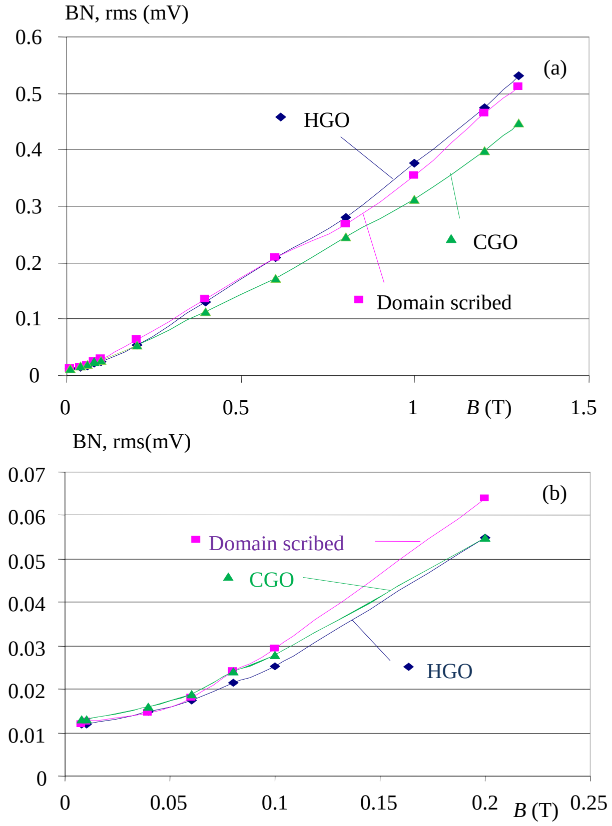

Fig. 6. (a) - Variation of average BN, rms of 10 strips each of CGO, HGO and Domain- scribed with peak flux density, (b) - Comparison in the low field regime

Further investigations are required to ascertain the number of domain walls that are active in these magnetization regimes in CGO and HGO steels.

Acknowledgement

The authors are grateful to the EPSRC for support of this research.

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Received 30 September 2010