Relationships between Barkhausen Noise and Power Loss

Knut HARTMANN, Werner RICKEN, University of Kassel, Kassel, Germany

Abstract. Non-destructive evaluation techniques like Barkhausen noise (BN) detection are important tools to determine material properties. Most previous investigation of BN has been carried out at frequencies up to a few Hertz. Due to the higher frequency measurements can be made within a few seconds and results are obtained rapidly. This paper demonstrates the strong relationship between Barkhausen noise and power loss at power frequencies.

Introduction

Barkhausen noise is generated by discontinuous irreversible changes in magnetisation within a magnetic material. The cause of these changes can be an irreversible domain wall motion interacting with e. g. inclusions or defects or a discontinuous expansion of a domain wall once its curvature has exceeded a critical value [1]. The BN phenomenon was discovered in 1917 by Professor Barkhausen and firstly published in 1919 [2]. The first few decades after BN was discovered not much research took place in that area. Nowadays, BN has found many applications in non-destructive testing [3].

Figure 1 shows a systematic sketch of a BN measuring system. The noise heard in the loudspeaker depends on the BN amplitude [4]. Also it is known that BN signals are broadband, weak and hence not easy to measure.

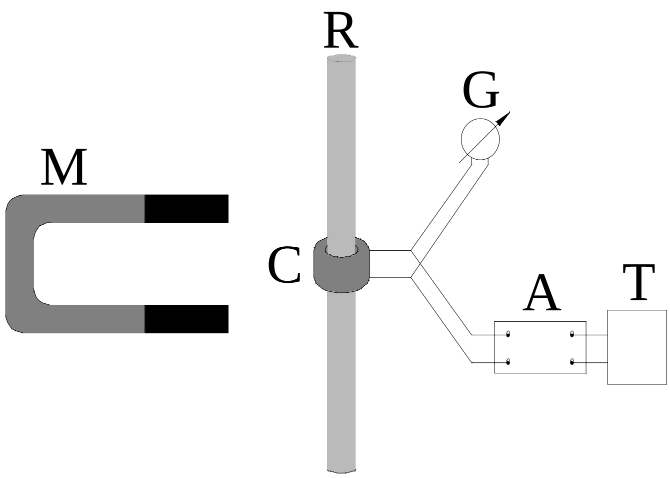

Figure 1: Original Barkhausen noise system; M: Magnet, R: Iron rod, C: Search coil, G: Galvanometer, A: Tube amplifier, T: Telephone

It is quite common to detect BN employing the induced e.m.f. method. This technique mostly uses two search coils connected in series opposition to eliminate the Faraday e.m.f. which usually is many order of amplitude greater than the BN component.

This paper describes different BN parameter being measured and their suitability to be correlated with material characteristics, namely the Power Loss of electrical steel strips which have been investigated.

Measurement system and evaluation

Figure 2 shows the schematic outline of the BN measuring system. Measurements took place under shielded conditions. The function generator was battery driven. The main component is the double search coil connected in series opposition. The differential output is then fed into an A-D card.

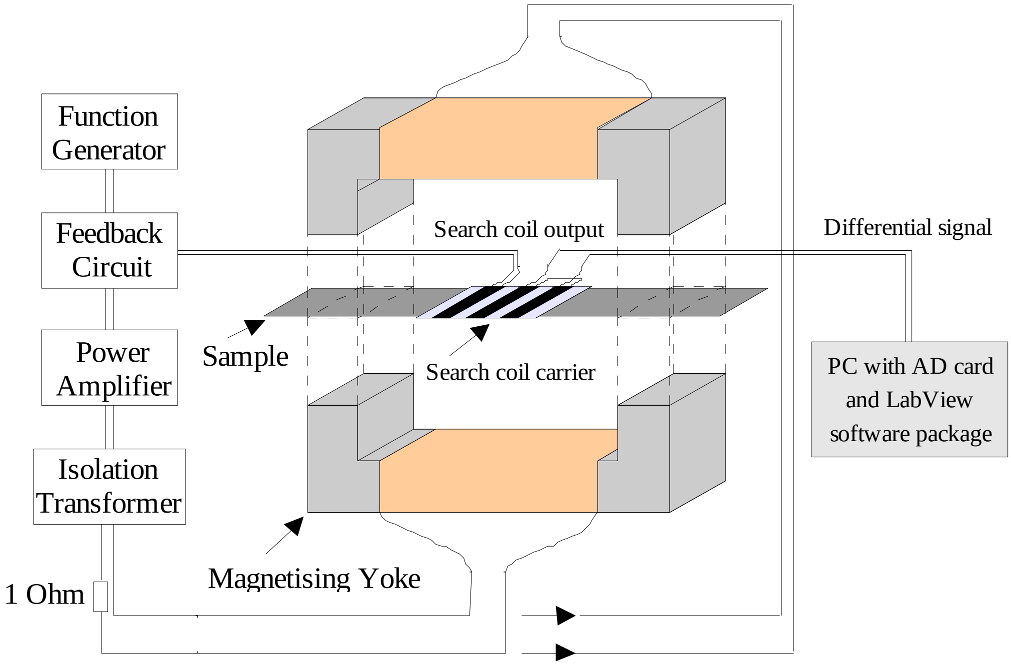

Figure 2: Barkhausen noise measuring system

A typical BN spectrum with a peak flux density of 900 mT and a magnetising frequency of 50 Hz can be seen in Figure 3. When the magnetising frequency is increased, the Faraday e.m.f. increases as well. Figure 3 shows that the Faraday e.m.f at 50 Hz is typically 3500 times higher than the BN.

The specimen was an electrical steel strip with a width of 30 mm and a thickness of 0.27 mm. The output 50 Hz fundamental from each search coil is around 124 mVrms at a peak flux density of 900 mT.

The maximum Barkhausen noise peaks in Figure 3 are around 60 µV. Digital signal processing was carried out within LabVIEW. A digital 4^{th} order Butterworth filter with a cut off frequency of 2500 Hz was used to eliminate the 50 Hz e.m.f. component and its harmonics.

Also a digital threshold of ±4 µV was applied to the BN signal to reduce noise which may rise from other external sources as well as any spurious noise signals from the system itself. The measurements have been carried out in a shielded room.

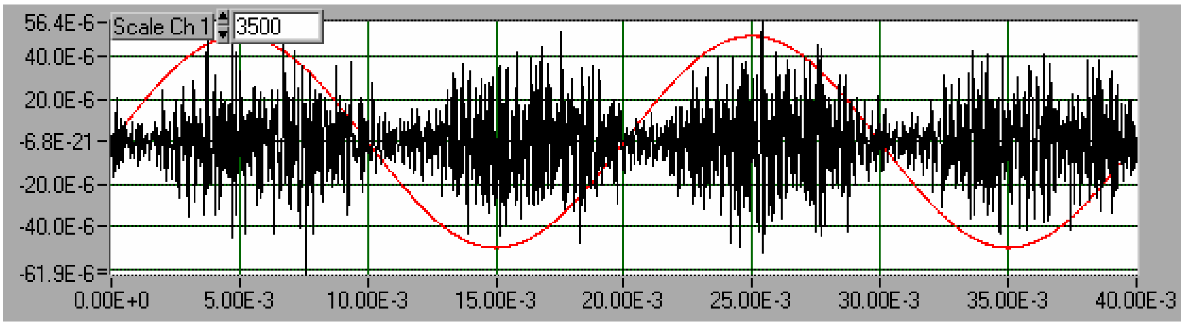

Figure 3: Barkhausen noise amplitude versus time captured over two cycles.
The red curve shows the dB/dt voltage (3500 times smaller)

The BN spectra can be considered as a stochastic signal. Hence, it is necessary to analyse theses signals in an appropriate way to show repeatability for successive measurements. All examined BN parameters have been calculated from 20 consecutive cycles according the following equation:

$$BN\ parameter = \sum_{i=1}^{z=10} \left(\sum_{k=1}^{m} \left(|a_k| \right) \right)_i \qquad \text{(Eq. 1)}$$

In Equation 1 variable ‘a’ represents the amplitude of the measured data point, index ‘k’ shows its position within the measured data point array ‘m’. Variable ‘z’ indicated that this measurement has been taken ten times sequentially. Index ‘i’ displays how often the measurement has been carried out. Finally all BN parameters have been measured three times and were compared subsequently. The following BN parameters have shown repeatability and are used to demonstrate the relationship between BN and power loss.

- Total Sum of Amplitudes (TSA1) which is meant to be the sum of the absolute amplitudes which are greater than the chosen threshold of ±4 µV. This parameter is linked to the ‘Absolute Mean’ which can be obtained when TSA1 is divided by the number of data points which passed the threshold.

- Power Spectrum is calculated within LabVIEW. When the power spectrum is plotted within the frequency domain it is mirrored at half of its spectrum. This has been taken into account and a single sided or auto power spectrum is being plotted. The plot of the power spectrum does not show repeatability but the sum of the power obtained from each frequency component does.

- RMS is the root mean square of the signal which has been calculated within LabVIEW according Equation 2.

$$rms = \sqrt{\frac{1}{N} \sum_{i=0}^{N-1} x_i^2} \qquad \text{Eq. 2)}$$

Results

Analysing the relationships between BN and power loss can be carried out in different ways. Either the increase at the different flux densities referring to a certain reference value e.g. at 0.1T or 0.2T can be monitored or the results can display the step to step increase of the BN parameter when the flux density is increased from e.g. 0.1T to 0.2T or from 0.2T to 0.3T etc. How this step by step increase (and the resulting step factor) is determined is displayed within Table 1.

Referring to a single reference value seems to be less useful as the complete results depend on the accuracy of one single measurement. Especially if the reference is the measurement taken at a peak flux density of 0.1T results are not reliable. This is because at such a small peak flux density BN just starts to occur and consecutive measurements may vary significantly.

B max [T]	Parameter			Step Factor
0.1	1.240E-2			-
0.2	4.163E-2	4.163E-2 / 1.240E-2 =		3,36
0.3	7.094E-2			1,70
0.4	1.030E-1	•		1,45
0.5	1.362E-1			1,32
0.6	1.681E-1	•		1,23
0.7	2.019E-1			1,20
0.8	2.421E-1	•		1,20
0.9	2.871E-1			1,19
1.0	3.289E-1	•		1,15
1,1	3.861E-1			1,17
1.2	4.481E-1	•		1,16
1,3	5.229E-1			1,17
1,4	6.250E-1	6.250E-1 / 5229E-1 =		1,20

Table 1: Step factor determination to relate BN with power loss

Figure 4 presents the step factor comparison between TSA1 and power loss versus peak flux density.

Figure 5 shows the step factor comparison between the power spectrum of the BN and power loss versus peak flux density.

Figure 6 displays a comparison between the RMS and power loss versus peak flux density can be seen.

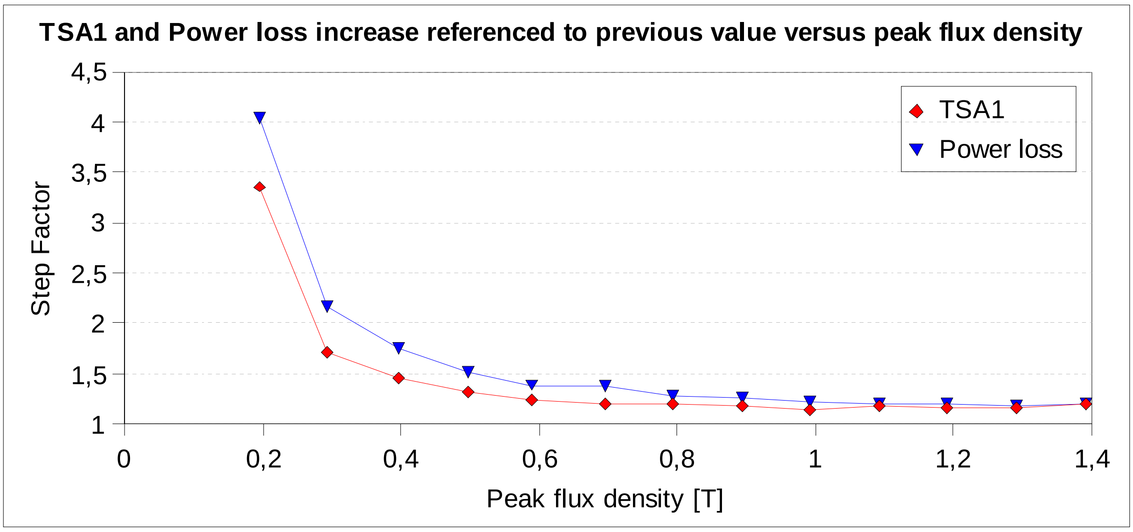

Figure 4: Step factor comparison between TSA1 and power loss versus peak flux density

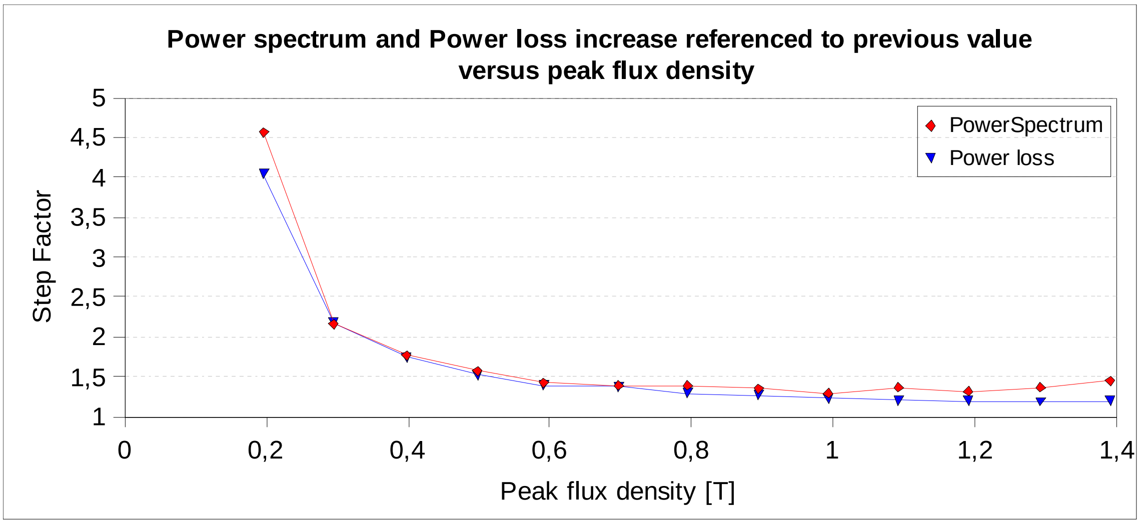

Figure 5: Step factor comparison between Power spectrum and power loss versus peak flux density

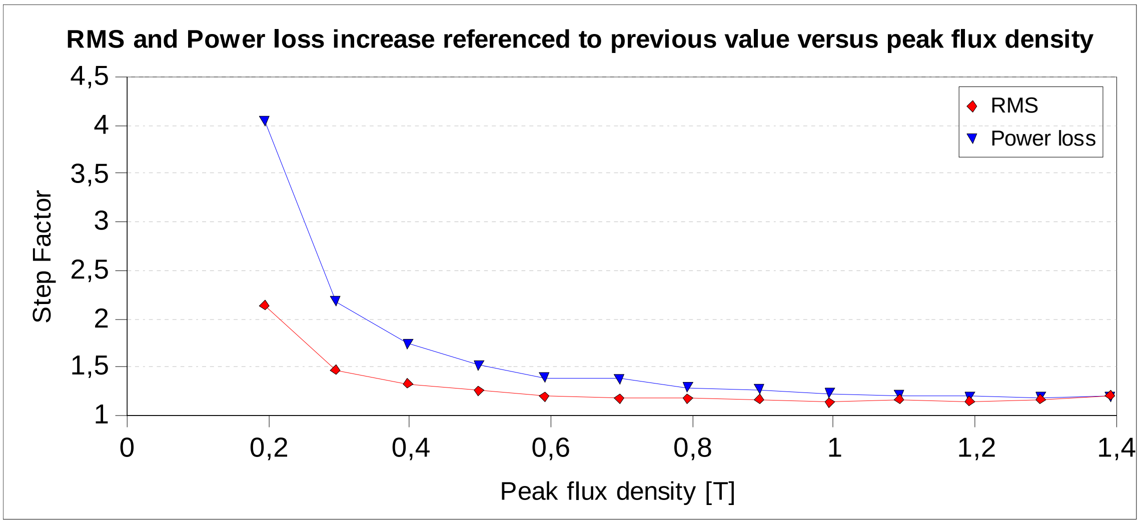

Figure 6: Step factor comparison between RMS and power loss versus peak flux density

Discussion

Comparing TSA1 and power loss the step factor decreases with increasing flux density. This means that the growth of amplitudes reduces permanently with increasing flux density. At a peak flux density of 0.4T the increase of amplitudes compared to 0.3 T can be determined as 1.45 for TSA1, for the power loss a factor of 1.75 can be calculated. At a peak flux density of 1.2T the step factor by which the amplitudes are increasing compared to a peak flux density of 1.1T is 1.16 for TSA1 and 1.19 for the power loss. The percentage difference between the calculated step factors for TSA1 and power loss at 0.4T is 20.4%, at 1.2T a difference 2.9% can be derived. If all percentage differences are calculated the first acceptable difference of 7% can be found at 0.8T. Below that peak flux density all values for the percentage difference are higher than 10%.

The step factor of the BN power spectrum decreases up to a peak flux density of 1.0T, if the flux density is increased further a small increase can be recognised. The increase at 1.4T compared to the value at 1.0T is 12.4%. The step factors from 0.3T to 1.0T within Figure 5 show a percentile difference less than 6%. Above a flux density of 1.0T the difference in the step factors increases and has its maximum difference at 1.4T with 17.5%. At a peak flux density of 0.4T the increase of amplitudes referred to 0.3T is 1.77 for the power spectrum and - same as above – 1.75 for the power loss. Comparing the step factors this is a difference of (-)1.35%. At a peak flux density of 1.2T the power spectrum has a step factor of 1.32 and power loss 1.19. The difference has increased and can be calculated as 9.4%.

Step factors for the RMS behave similar as for TSA1. At 0.4T the step factor is 1.33 which is a difference of 31.3% to the step factor of the power loss. At 1.2T the RMS has a step factor of 1.15 which gives a difference of 4.0% compared to the power loss step factor. Considering all percentage differences the first value less than 10% can be found at 0.8T and has a value of 8.9%.

Conclusion

BN spectra have been measured at power frequency and show reproducibility for the discussed parameters. Nevertheless screening and the usage of low noise components was essential to obtain the signal.

BN measurements can be related to power loss. The curves representing the step factors and the curves describing the power loss show a similar characteristic. It is not possible to determine absolute values of the power loss. Nevertheless, if the power loss at a certain peak flux density is known (e.g. at 0.4T) then it seems possible to derive the power loss at e.g. 1.0T from the BN measurements. A prediction of power loss increase through the magnetisation process is possible.

Comparing the step factors of the three BN parameters they show different values. Some of them are very close to the step factors of the power loss others show a variation of 20% and more. When the power loss increase is derived from BN parameters it might be convenient to have similar step factors for the BN parameter and the power loss. This would allow a direct reading of the power loss increase without introducing further calculations.

Up to a peak flux density of 1.0T this can be achieved when the step factor of the power spectrum is used. Above 1.0T the step factors of TSA1 are very close to the step factors of the power loss with a percentile difference better than 6%.

References

[1] D.C. Jiles; Introduction to Magnetism and Magnetic Materials; Chapman & Hall; ISBN 0-412-38630-5

[2] H. Barkhausen; Geräusche beim Ummagnetisieren von Eisen; Phys. Z. 20 (1919) 401-402

[3] T.W. Krause, D.L. Atherton; NDT & E International (1994) Vol 27, No. 4, 201

[4] R. M. Bozorth; Ferromagnetism; IEEE Press (1978)