# BARKHAUSEN NOISE ANALYSIS BY SURROUNDING COIL

J. Catty, P. Fleischmann and J. Chicois
GEMPPM, Bat.303, U.A 341, INSA
69621 Villeurbanne Cedex, France

A. Le Brun
EDF -DER /REME
25 Allée Privée, Carrefour Pleyel
93206 St-Denis Cedex 1, France

## INTRODUCTION

The Barkhausen effect (or Barkhausen noise)[1], discovered in 1919, was initially identified as the revealing of irreversible and discontinuous changes of magnetisation induced by an external magnetic field[2]. The interest of Barkhausen noise as a non destructive testing technique of magnetic materials is due to the interaction between the magnetic microstructure (magnetic domains, Bloch wall motion dynamic), microstructural state and stress state of the material [3,4,5,6].

In this work, we try to obtain a more detailed insight into Barkhausen noise measuring mechanisms. We study the influence of the coil configuration on the measurement. We will try to answer the questions: What is the influence of a gap between the coil and the sample? What is the influence of the geometrical characteristics of the measuring coil? Finally, a model that explains qualitative and quantitative effects will be presented.

## EXPERIMENTAL

The function of the device is to magnetise a sample from saturation to saturation with an alternating magnetic field (+/-20 KA/m) and to process the signal coming from the encircling detection coil in order to extract Barkhausen noise and the hysteresis cycle (Fig 1).

1) In order to create the saturation field in the sample, we use a mu-metal inductor, an alloy of very weak remanence and high permittivity. The inductor is of a large section compared to that of the sample. A triangular waveform current (+/- 2 A) is applied to the inductor coil at a frequency of 0.1 Hz. We suppose that the field H in the sample is proportional to the current "I" in the inductor coil.

2) The measuring transducer is an encercling coil of 150 turns that delivers an electric signal proportional to the flux variations in the axis of the sample. A wide-band preamplifier (gain = 25) located fairly near the transducer amplifies the signal high enough to be processed. This gives the following information (Fig 2):

a) After preamplification, the signal is quantified by its maximum absolute value $e_{max}$;

b) The high frequency part (> 500 Hz) of the preamplificated signal is the Barkhausen signal. It must be amplified (gain = 100) to be processed. Usually we quantify it by its Root Mean Square value (RMS) with an integration period T=25 msec.

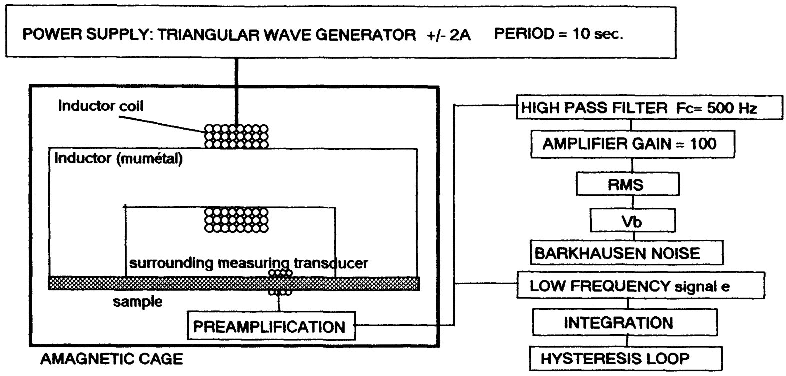


Figure 1 Experimental equipment.

In this paper, we have plotted the relative variations of the maximum value $Vb_{max}$ of the Barkhausen signal. Measures are carried out on a parallelepiped steel sample (%C = 0.1) of section 4×10 mm$^2$. In order to be able to compare the results together and verify reproducibility of the experiment, we also measure the signals from an encircling coil composed of two layers of 75 turns.

## TYPICAL EXPERIMENTS

### Distance Between the Coil and the Sample

The constitution of the detection coil is shown in Fig. 3.

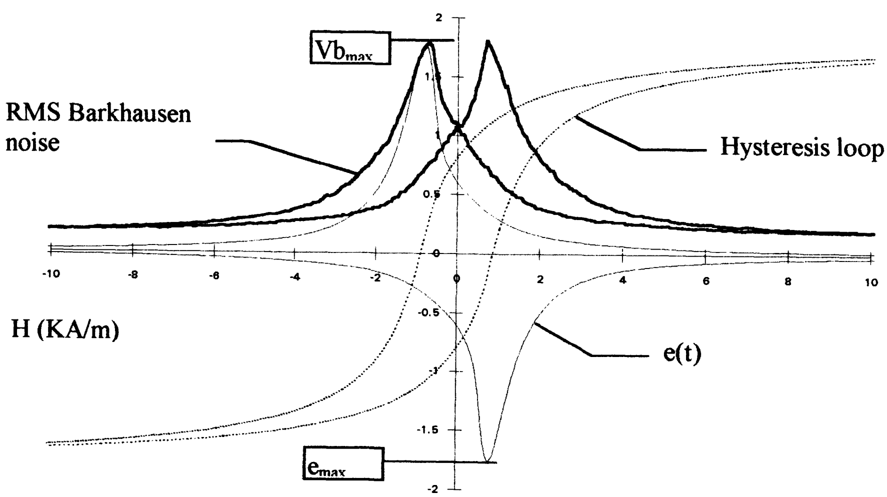


Figure 2 Typical hysteresis loop and Barkhausen noise.

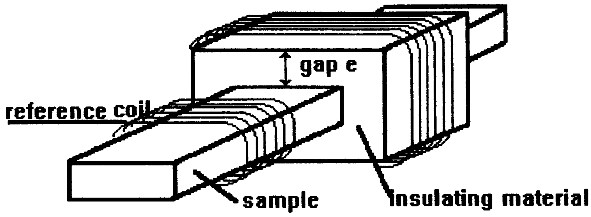


Figure 3 Coil at a distance « e » from the sample.

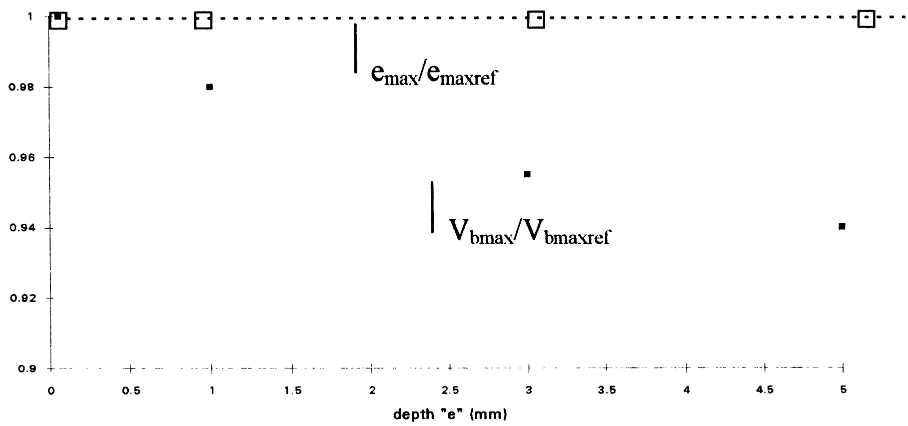


Figure 4 Influence of the distance between the coil and the sample.

Conclusions:

1) The low frequency part of the flux delivered by the inductor is mainly confined in the sample: no variation of $e_{max}$

2) A small decrease of Barkhausen signal is observed when the distance between the coil and the sample increases, without any shift of the peak position. It can be explained by a local rebuckling of some flux lines through the air of the gap. This experiment shows that this rebuckling of flux lines through the air is located very near the surface (5 mm).

Influence of the Coil Transducer Length

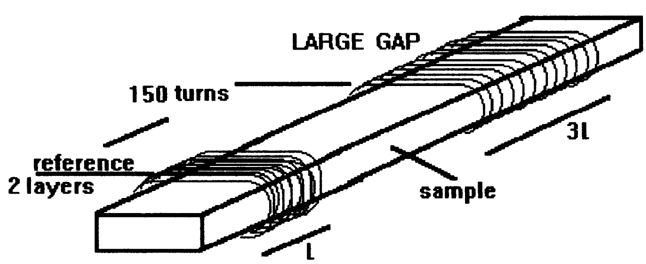


Figure 5 Constitution of the detection coil.

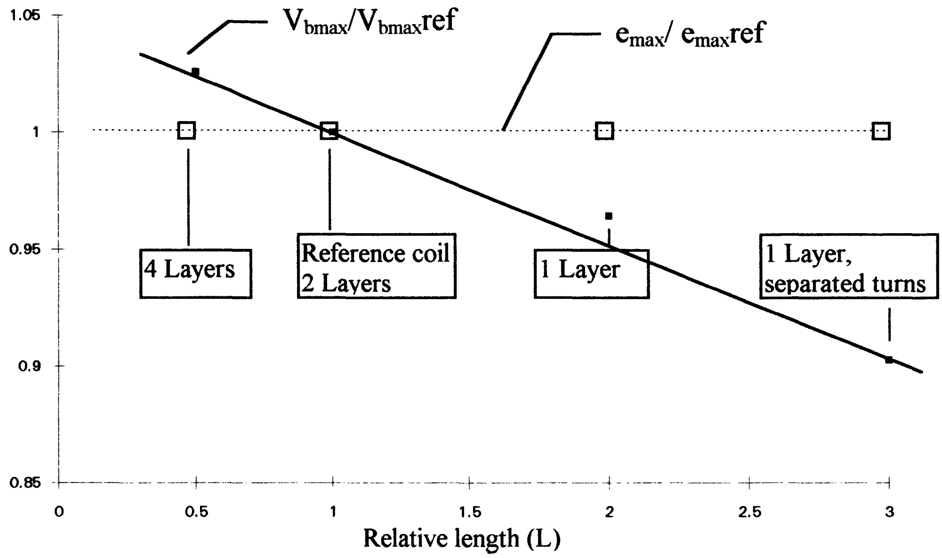


Figure 6 Influence of the relative length of the detection coil on the amplitude of the Barkhausen signal.

Conclusions (Fig 6):

1) The low frequency signal does not depend on the relative length of the coil

2) The maximum amplitude of the Barkhausen signal decreases as the length covered by the detection coil increases.

Detection Coil Composed of Two Parts

In order to quantify the phenomenon responsible for the decrease of the Barkhausen signal in the precedent experiment, we built a transducer composed of two coils of 75 windings, each coil wound very closely.

* a serial transducer is composed of two parts wound in the same direction.

* a differential transducer is obtained if the two parts are wound in the opposite direction.

We gradually moved one part of the coil away from the other up to 40 mm.

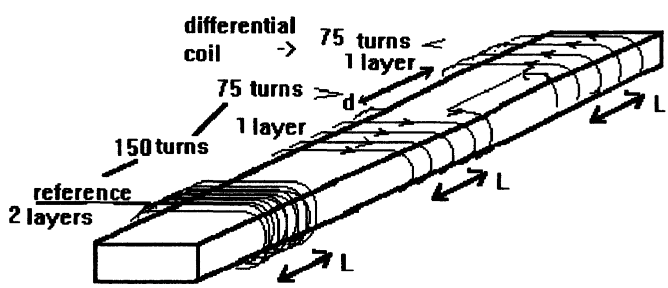


Figure 7 Two part coil: differential transducer.

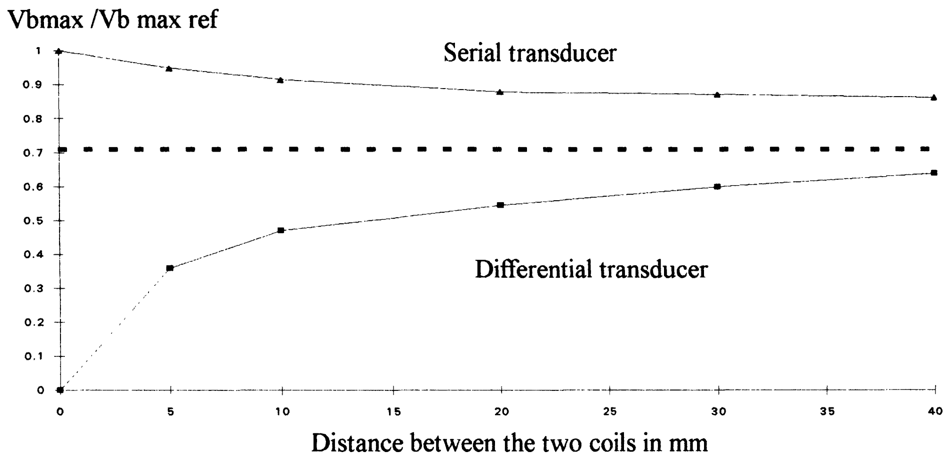


Figure 8 Influence of the distance between the two parts of a differential or « series » coil on the Barkhausen signal.

The following results are obtained (Fig 8):

1) Differential coil: (low frequency signal = 0). We observe an increase of amplitude of the Barkhausen signal with the distance between the two parts of the coil, without any shape variation of the Barkhausen signal versus time. It seems that the maximum peak amplitude reaches an asymptotic value, about 0.7 times the reference signal. At 40 mm, this value is not reached.

2) Serial coils: We observe a decrease of the amplitude of the Barkhausen signal with a distance increase between the two parts of the coil.

INTERPRETATIONS

The guide line for interpretation is that the Barkhausen amplitude of the signal given by each turn of a coil is to be added together on the frequency domain. A strong coherence exists between the signal given by each turn if caused by the same Barkhausen event in the material. We will consider that each elementary Barkhausen event « i » emits an electromagnetic signal. A turn « j » of the transducer generates a contribution to the voltage $e_{ij}(t)$ corresponding to the Barkhausen event i, in accordance with the Lenz law: $e_{ij}(t) = -n \times (d\varnothing_i/dt)$. The signal $e_{ij}(t)$ will be designated by $e_{ij}(\omega)$ in the frequency domain.

The following parameters must be taken into account to explain these results. The distance between a Barkhausen event and the turn that records the corresponding flux variation has a consequence on the measurement.It is quantified by an attenuation factor $\alpha(d,\omega)$, ($\omega=2\pi f$, f represents the observation frequency of the phenomenon), and a delay term $\tau ij$ (time of propagation) due to the propagation. At low frequency, the whole flux is confined to the closed magnetic circuit: $\alpha(d,0) = 1$. At an infinite distance and high frequency range $\alpha(\infty,\omega)=0$.

In the frequency domain, we can translate the Barkhausen event into a quantitative form:

$$e_{ij}(\omega) = K_i \, e^{-j\omega t_i} \, \alpha(d_{ij},\omega) \, e^{-j\omega\tau_{ij}} \quad (1)$$

- $\tau_{ij} = d_{ij} / V$ : delay due to propagation (V is the propagation speed)
- $K_i \, e^{-j\omega t_i}$ : represents the Barkhausen event that occurs at the time $t_i$
- $\alpha(d_{ij},\omega) \, e^{-j\omega\tau_{ij}}$ : represents the effect of the propagation between the source i and the measuring coil j, separated by the distance $d_{ij}$.

We will suppose that the term $e^{-j\omega\tau_{ij}}$ is near to one; it follows that in the frequency range of the Barkhausen measurement $d_{ij}$ is very weak compared to the wavelength in our tested sample.

Calculation of the Coil Voltage

* In order to compare the experimental results with the simulation results, we have to calculate the energy E measured during the integration period T of the RMS ($V_{rms} \propto \sqrt{E}$):

$$E = \int_0^{\infty} S(\omega)d\omega, \qquad S(\omega) = \sum e_{ij} \times \sum e_{ij}^* \text{ : spectral energetic density.} \tag{2}$$

* When the gap between turns is very small, a coil composed of n turns "j" measures a single Barkhausen event "i" located at the distance $d_{ij}$ according to:

$$\sum_{j=1}^{n} e_{ij} = nK_i e^{-j\omega t_i} \alpha(d_{ij}, \nu) \tag{3}$$

* When a single turn "j" measures "m" Barkhausen events "i",

$$ej = \sum_{i=1}^{m} e_{ij} = K_1 e^{-j\omega t1} \alpha(d_{1j},\omega) + K_2 e^{-j\omega t2} \alpha(d_{2j},\omega) + \ldots + K_m e^{-j\omega tm} \alpha(d_{mj},\omega) \tag{4}$$

Supposing that the events are decorrelated in time, we lead to

$$S(\omega) = K_1^2 \alpha^2(d_{1j},\omega) + K_2^2 \alpha^2(d_{2j},\omega) + \ldots + K_m^2 \alpha^2(d_{mj},\omega) \tag{5}$$

Calculation of the Coil Voltage with a Gap between the Turns

We suppose that the turns are separated one from the next by a distance gap $d_0$, and that the event "i" is generated at the distance $d_i$ from the nearest turn. By distributing the position of events uniformly on a sample of infinite length, we obtain:

$$\begin{aligned} S(\omega) = {} & K_1^2 [\alpha(d_1,\omega) + \alpha(d_1 + d_0,\omega) + \ldots + \alpha(d_1 + (n-1)d_0,\omega)]^2 + \ldots + \\ & + K_m^2 [\alpha(d_m,\omega) + \alpha(d_m + d_0,\omega) + \ldots + \alpha(d_m + (n-1)d_0,\omega)]^2 \end{aligned} \tag{6}$$

Fig. 9 shows the curve obtained after numerical simulation ($\alpha(d) = 1/d$):

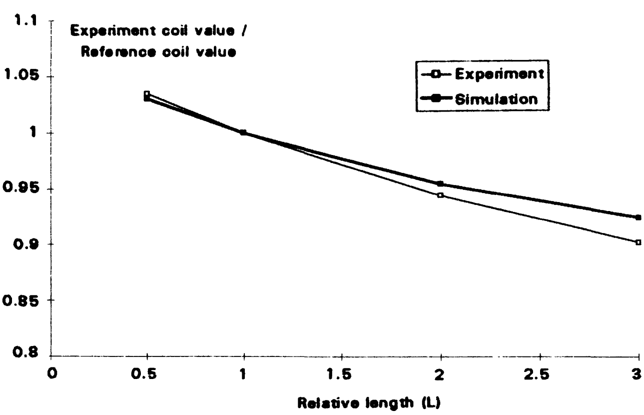


Figure 9 Comparison between experiment and simulation of RMS voltage variations related to the gap between turns.

Calculation of a coil voltage composed of 2 parts

When the coil is in two parts, "a"( $n_a$ turns) and "b"( $n_b$ turns), separated by a distance $d_o$, each part with a negligible gap between turns, the signal is then the sum or the difference between $e_a$ and $e_b$ from each coil. If we consider m events uniformly distributed in the sample and that events are decorrelated, this leads to:

$$S(\omega) = \sum_{i=1}^{m} K_i^2[n_a\alpha(d_{ia},\omega) - n_b\alpha(d_{ib},\omega)]^2 \text{ if coils are connected in opposition}$$
$$S(\omega) = \sum_{i=1}^{m} K_i^2[n_a\alpha(d_{ia},\omega) + n_b\alpha(d_{ib},\omega)]^2 \text{ if coils are connected in series} \quad (7)$$

* When coils are superposed, $\alpha(d_{ia},\omega)=\alpha(d_{ib},\omega)$ for every event i. If $n_a = n_b = n$, $S(\omega)$ becomes:

$S(\omega) = 0$ if coils are connected in opposition

$$S(\omega) = 4n^2 \sum_{i=1}^{m} K_i^2\alpha^2(d_i,\omega) \text{ if coils are connected in series} \quad (8)$$

* If coils are very far from the other, they would not be sensitive to the same events. If an elementary event is picked up by the first coil, $\alpha(d1) \neq 0$ et $\alpha(d2) = 0$ and reciprocally. Then, $\alpha(d1) \times \alpha(d2) = 0$ whatever the event. The RMS signal is then

$$S(\omega) = 2n^2 \sum_{i=1}^{m} K_i^2\alpha^2(d_i,\omega) \quad (9)$$

This means that the RMS signal is the same, even if the coils are connected in series or in opposition.

The simulation (Fig10) is similar to the experimental results shown in Fig. 8. Meanwhile, the quantitative aspect is different the between experimental results and calculated values. We have to adjust the function $\alpha(d,\omega)$ to the experimental results. It seems that this function decreases slower than 1/d.

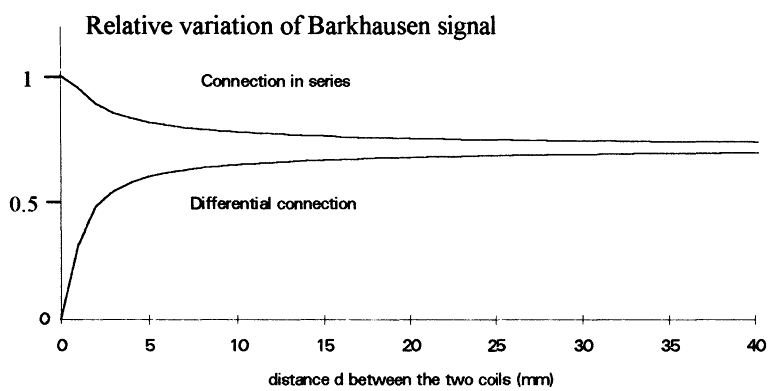


Figure 10 Numerical simulation of the voltage from two coils connected in series or in opposition in terms of distance between the two coils.

CONCLUSIONS

Barkhausen noise analysis using a surrounding coil enables us to measure very easily the flux variations in the sample in accordance with the Lenz law. The first experiment showed a type of rebuckling of flux lines near the surface of the sample. Two experiments show clearly the influence of the distance between the turns (or the coils) on the Barkhausen noise:

1) With the same number of turns, the longer the sample covered by the transducer, the smaller the Barkhausen signal.

2) A transducer composed of two coils of 75 turns wound in the same direction (series transducer) or in the opposite direction (differential transducer) has been studied. When we increase the distance between the two parts, the Barkhausen signal increases (differential transducer) or decreases (series transducer). When the distance is sufficiently large (more than 40 mm), we reach an asymptotic value.

In order to explain these results, we propose a simple model, considering that each elementary Barkhausen event « i » emits an electromagnetic signal, generating a voltage $e_{ij}(t)$ in the turn. The electric voltage from a single winding is the result of the addition in the frequency domain of these elementary events. The correlation between each elementary Barkhausen event is taken into account. We also suppose that a Barkhausen event is attenuated by a factor $\alpha(d,\omega)$ ($\omega=2\pi f$, pulsation of the phenomenon) due to the propagation (d: distance between the event and the turn). Calculating the energy E measured during the integration period T of the RMS , we obtain a good correlation between experimental and numerical simulation. However, it seems necessary to quantify the term $\alpha(d,\omega)$.

ACKNOWLEDGEMENTS

Financial support from Electricité de France is gratefully acknowledged.

REFERENCES

1. Barkhausen, H. Zwei mit Hilfe der neuen Verstärker entdeckte Erscheinungen. Phys. Z., 1919, Vol. 20, p. 401-412.
2. Herpin, A. Théorie du magnétisme. Paris: INSTN-PUF, 1968. 683 p.
3. Tiitto, S. On the influence of microstructure on magnetisation transitions in steel. Acta Polytechnica Scandinavica., 1977, Vol. 119, 80 p.
4. Tiitto, K. Use of Barkhausen effect in testing for residual stresses and material defects. Residual Stress in design, process and materials selection, Cincinnati, Ohio, USA, 27-29 Apr. 1987, p 27-36.
5. Jagadish C., Clapham L., Atherton D.L. Influence of uniaxial elastic stress on power spectrum and pulse height distribution of surface Barkhausen noise in pipeline steel. IEEE transactions on magnetics, 1990, Vol 26 (3), p. 1160-1163.
6. Clapham L., Jagadish C., Atherton D.L., Boyd J.D. The Influence of Controlled Rolling on the Pulse Height Distribution of Magnetic Barkhausen noise in Steel. Materials Science and Engineering, 1991, A145, p. 233-241.