# Characterization of the Magnetic Noise Barkhausen Using Wavelets Transform

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***Abstract.*** *The development of trustworthy methods for the evaluation of materials used in structural components has become of great interest for the programs of evaluation of structural integrity and extension of the life. Amongst these methods the method of assay based on analysis of the Barkhausen signal emitted for ferromagnéticos materials how submitted of an influence of a variable magnetic field.. This work presents a method of processing of Barkhausen signals using transformed Wavelets as alternative to analyzes using RMS value of the noise.*

***Keywords****: Barkhausen effect, classification of materials, decomposition to multiscale, analysis of regression, transformed Wavelets.*

## 1. Introduction

Recently has had a great development in the magnetic methods for the characterization of ferromagnetic materials, being able to be applied in the evaluation of the conditions of the biggest part of used steel. Among the magnetic methods, the method of assay based on the analysis of the Barkhausen signal, emitted for submitted ferromagnetic materials to the influence of a magnetic field in specific conditions. The signal originates from the interaction that occurs between the magnetic domain and the existing structural compositions in the interior of the material during the magnetization process. This signal is sensible to the microstructural alterations being, for example, used for the determination of the level of tensions applied in the material (Junior, 1998).

The development of the microelectronic and processing of signals has allowed an efficient interpretation of the methods of non destructive testing, especially for the method of Barkhausen assay.

This work aims at presenting a tool of alternative characterization of the Barkhausen noise to the RMS for the use of Entropy Shannon Wavelet, a powerful tool of signal processing usable to show the variations of the amount of information given in the signals under tension shipments and compression.

The information gotten for the considered method is used in a statistical analysis the model of possible Linear Regression becoming the differentiation of 3 samples of materials, a priori strangers.

## 2. Barkhausen Effect

The magnetic properties of the magnetic materials are dependent basically of their chemical composition and the process used in their manufacture, including the type of mechanical processing and necessary thermal treatments to their attainment.

Other properties, as the permeability, the coercive force and the loss for hysteresis are extremely sensible to the variations that occurs in these characteristics of the materials, allowing that they are used as tools for the non-destructive evaluation of ferromagnetic materials. The ferromagnetic materials possess small similar magnetic regions, the small magnets, called magnetic domain (Junior, 1998). When a magnetic field is applied to a sample of a ferromagnetic material, the domain tends to modify its original position in direction to a new position, more steady in function of the presence of the external magnetic field, Figure 1.

The movement of the domains in direction to the new position of balance does not happen soft form, but discontinous form to the measure where increases the applied magnetic field strength to the material and if it covers its curve of magnetization. These discontinous changes that occur in the magnetization curve due to the abrupt movements of the domain can be detected through a bobbin located next to the material, therefore they will go to induce electric pulses in the same one. These electric pulses, produced for the discontinous movement of the domains are called signals or Barkhausen noises, Figure 2, that which was first observed the phenomenon in 1919 [ PASLEY, 1969 ].

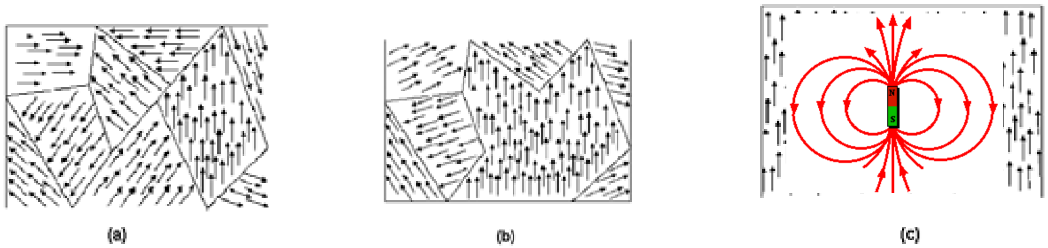


Figure 1. Movement of the borders of domain to favor the alignment and growth of the domains in function of the applied magnetic field. (a) Absence of magnetic field. (b) Presence of magnetic field. (c) Presence of a maximum magnetic field representing the saturation of the domain (Jiles, 1998).

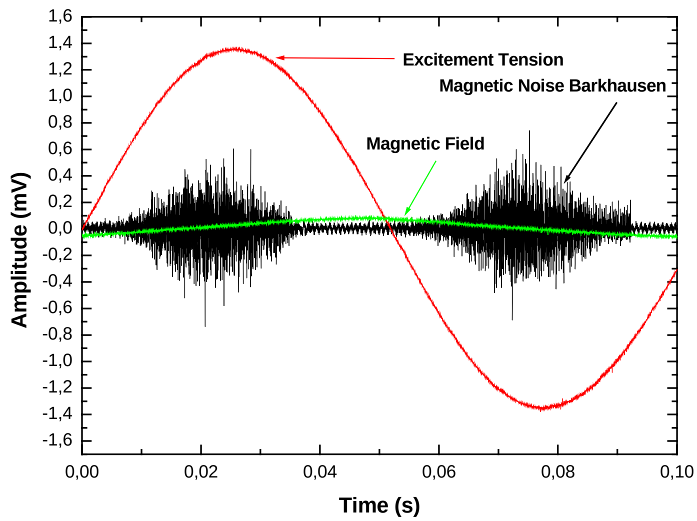


Figure 2 - Magnetic signal Barkhausen gotten of one sample of steel ASTM A 515. The figure illustrates the tension of excitement and the magnetic field applied to the sample and emitted correspondent RMB.

Two important characteristics affect the intensity and nature of the Barkhausen signals. The first one is the presence of elastic tensions in the material, that they intervene with the form with that the magnetic domain will go to put into motion of a direction of easy magnetization for, being the interaction between the elastic tensions and the present structure of domain, so called magnetoelastic interaction of the material.

## 3. Wavelet Transform

### 3.1. Discrete Wavelet Transform

The Discrete Transform (DWT) uses parameters of discrete scheduling and translation being defined as (Parraga, 2002):

$$DWT_{(m,p)} = d_{m,p} = \int_{-\infty}^{\infty} f(t).\Psi_{m,p}\,dt$$

where $\Psi_{m,p}$ forms a base of Wavelets functions in accordance with the Wavelet function mother from the parameters of discrete scale and translation ( $m$ and $p$ , respectively).

This way, $\Psi_{a,b}(t)$ is given by:

$$\Psi_{m,p} = \frac{1}{\sqrt{a_0{}^m}}\Psi\left(\frac{t}{a_0{}^m} - p.b_0\right) = \frac{1}{\sqrt{a_0{}^m}}\Psi\left(\frac{t - p.a_0{}^m.b_0}{a_0{}^m}\right)$$

where $a_0$ and $b_0$ are constant $m$ and $p$ belong to the set of the whole number.

The parameters of dilate and translation are *m* and *p*, respectively. And the constants $a_0$ and $b_0$ give to the variation of the dilate and the step of the translation, respectively.

A choice made for the constants $a_0$ and $b_0$ are $a_0=2$ and $b_0=1$ (Parraga, 2002). This way, we have the dyadic Wavelet, showed a tax of $2^m$. Also it is chosen that the components $\Psi_{m,p}$ of the set of Wavelets functions are ortogonals and real functions. The function $\Psi_{m,p}$ will be orthogonal if, and only if:

$$\langle \Psi_{m,p}, \Psi_{m,k} \rangle = \delta(p-k) = \begin{cases} 1, & p = k; \\ 0, & p \neq k. \end{cases}$$

Then it is had that:

$$\Psi_{m,p} = \frac{1}{\sqrt{2^m}} \Psi\left(\frac{t-2^m.p}{2^m}\right); \quad m, p \in \text{ whole number.}$$

This way, the dilate scale is had as a power of two ($a_m=2^m$), and steps of translation of a step of the dilate scale ($b_p=2^m.p=a_m.p$). The reconstruction of the signal is given by the equation:

$$f(t) = \frac{2}{A+B}\sum_m \sum_p c_{m,p}\Psi_{m,p}(t)$$

An efficient way to apply this transformed is through filters, where it is had decomposition of the Wavelet implementing the analysis multiresolution that allows to analyze signals in multiple bands of frequencies (Mathworks, 2005).

This decomposition is responsible for removing from a signal the components of high and low pass-high frequency by means of filters and pass-low, decomposing the signal and implementing the analysis multiresolution that allows to analyze the signal in multiple bands of frequencies.

The Wavelet function $\Psi(t)$ is related to a pass-high filter which produces the coefficients of details of the Wavelet decomposition. Summing up, on has a function related to the pass-low filter, namely, scheduling $\phi(t)$ associated with the coefficients of approach of the Wavelet decomposition [Penna, 2002].

### 3.2. Transformed Wavelet Packet - TWP

The TWP is a generalization of the concept of the TWD and offers diverse possibilities of analysis of a signal, also the division of the details and of the approaches, also becoming possible the choice of which the best one enters the bases following some criterion of choice, having the best base, or excellent representation, to possess substantial information on the signal.

The TWP allows to the signal $s$ to be represented by the sequence *s=A1+AAD3+DAD3+DD2*. The best representation of a signal must take into consideration the entropy or cost of representation of this signal. Entropy is a common concept in signal processing, and represents the amount of information in bits/symbol necessary to represent a signal (Almeida, 2001). The best representation of a signal must take in account the entropy or cost of representation of this signal. How much higher the entropy of a signal, greater will be the amount of information that must be used for representing.

In this work, the Entropy Shannon Wavelet was used between an universe of functions a time that presented the great sensitivity with the variations of the Barkhausen noise emitted by steel samples under diverse shipments of carried through traction and compression. The Shannon entropy is defined as:

$$\varepsilon_X = -\sum_i \frac{|x_i|^2}{|x|^2} \log_2 \frac{|x_i^2|}{|x|^2}, \text{ where } |x|^2 = \sum_i |x_i|^2$$

where $\varepsilon_x$ represents the amount accomplishes of necessary bits for its representation.

## 4. Analysis of Regression

The regression analysis is a statistics methodology that uses the relations between two quantitative variable of such form that a variable can be predicted from another one: one, called changeable reply, or dependent, and another one, called explain variable, or independent. Known a set of values of the variable and the values associates of the changeable reply, one determines the parameters of the equation. The model is tested and gotten a reasonable equation, can uses it to differentiate materials for the reliable method of interval (Farias, Soares and Cesar, 2003).

In this work the model of simple linear regression for the reliable method of interval only to the stretch of the arched call of calibration that understands in the three samples the interval between -30 and +30 MPa is applied. The equation that defines this straight line is represented by two variable, tension (MPa), called explain variable and for Entropy(bits), predict variable call.

Although the observed points are not accurately on a straight line, the analysis of the data for the three samples approximately suggests a linear relation between the variable. The model that represents this set of points is given by (Pinto and Victer, 2005):

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

where $Y_i = \beta_0 + \beta_1 X$ is the equation of a straight line. Determined the parameters $\beta_0$ and $\beta_1$, to each value of $X_i$ the explain variable will correspond to a theoretical value $Y_i$ of the answer variable, that will be differentiated of the value observed for the error $\varepsilon$, where it

$$\varepsilon_I = Y_{observed} - Y_{theoric}$$

$\beta_0$ is the intersection with the axle of $y$ and $\beta_1$ is the angular coefficient or inclination of the straight line. The error $\varepsilon$ is a variable on which it makes the following assumptions (Draper and Smith, 1998):

i. $E(\varepsilon_I) = 0$ that is, the estimate of the errors makes use indifferently of a side or another one of the straight line;

ii. $Var(\varepsilon_I) = \sigma^2$ (population variance), or either, all the errors have the same variability;

iii. $cov(\varepsilon_I, \varepsilon_j) = 0$ for all i $\neq j$. Or either, the errors are not correlated, an error do not depend on any another error.

Reliable interval supplies estimates for the parameters of unknown intervals. One is about a method by means of which it can determine the limits of an interval that has one determined probability to contain the true value of a parameter among its limits.

### 3.2.1. Reliable interval for $\beta_1$

$$b_1 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})y_i}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad = \frac{x_1 - \bar{x}}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} y_1 + \frac{x_2 - \bar{x}}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} y_2 + \ldots + \frac{x_n - \bar{x}}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} y_n$$

$$Var(b_1) = \frac{x_1 - \bar{x}}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} Var(y_1) + \frac{x_2 - \bar{x}}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} Var(y_2) + \ldots + \frac{x_n - \bar{x}}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} Var(y_n)$$

As $Var(y_i) = \sigma^2$, then

$$Var(b_1) = \frac{\sigma^2}{s_{xx}}$$

the estimate of $Var(b_1)$ is: $\dfrac{s^2}{s_{xx}}$

Soon the reliable interval is: $b_1 = \pm \dfrac{t_{(n-2,\alpha)} s}{\sqrt{s_{xx}}}$

## 5. Instrumentation

The used basic equipment for the measurement of the Barkhausen signals was Stresstest 2004, of the Metalelektro, that allows the use of frequencies excitement of 10 and 100 Hz (Metalelektro, 1995) and incorporates a microcomputer for control of the test variable and acquisition of data.

For the accomplishment of the measures of the magnetic signal Barkhausen only one sounding lead used, responsible was for the excitement of the material and the detention of the generated Barkhausen signals in the interior of exactly, associated to the equipment of measure of Barkhausen signals that is responsible for the operation of the sounding lead of the acquired signal. The sounding lead incorporates a unit of magnetization and a sensory bobbin, as indicated in Figure 3.

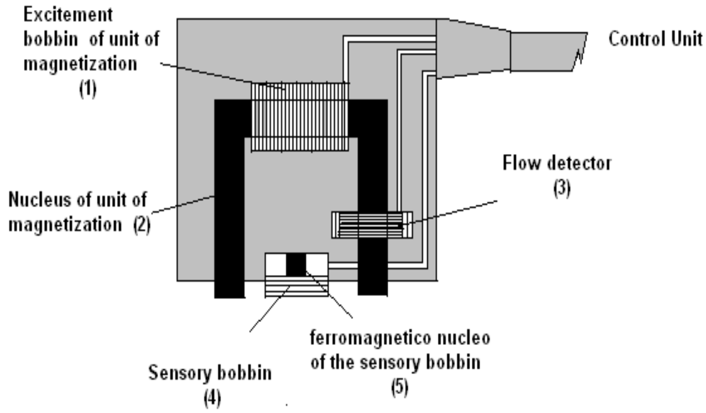


Figure 3 - Schematical drawing of one investigates characteristic for the excitement of the material and detention of the magnetic signal resultant Barkhausen.

The equipment of measurement of the Barkhausen signals is connected a powerful plate of acquisition of data with sixteen analogical channels of entrance installed in a microcomputer Pentium III 650 MHz, capable to acquire data to a tax of 1.25 million samples for second with resolution of 12 bits. A channel for reading of the magnetic noise Barkhausen, a channel for the reading of the excitement tension and one third canal for reading and monitoring of the magnetic field of excitement had been used.

## 6. Materials

The materials used in this research are ASTM A 515, AISI 1045 and SAC 50. These materials relate to the steel used in the manufacture of boilers and vases of pressure for work in averages and high temperatures, supplied for the USIMINAS. The chemical composition and the mechanical properties of these materials are indicated in Table I.

Table I - Chemical composition of steel supplied for the manufacturer

| Material | Chemical Composition | | | | | Mechanical Properties | |
|---|---|---|---|---|---|---|---|
| ASTM Specification | C %max. | Mn %max. | Si % | P % max. | S % max. | $\sigma_r$ MPa | $\sigma_e$ MPa |
| A 515 | 0,28 | 0,90 | 0,15-0,30 | 0,035 | 0,040 | 380-515 | 205 |
| AISI 1045 | 0,42~0,50 | 0,60~0,90 | 0,10~0,25 | 0,040 | 0,050 | ~560 | ~300 |
| SAC 50 | 0,12 | 1,14 | 0,29 | 0,021 | 0,012 | ~522 MPa | ~400 MPa |

Had been manufactured three beams from the removed plate samples of the material to test, called isoflex beams. To guarantee a uniformity in the materials the beams had been manufactured in way that the longitudinal axle was parallel to the direction of lamination of the plate.

## 7. Results

In this paper are presented the results gotten in this work for the use of Wavelet Transform for analysis of the RMB emitted for the steel samples SAC 50, AISI 1045 and ASTM the 515 on diverse shipments of tensions.

Table II - Values of the analysis of regression for reliable interval for the data of the RMB for the method of Entropy of sample ASTM A 515.

| | Coefficients | Error Standard | 95% Inferiors | 95% Superiors |
|---|---|---|---|---|
| Intersection | 216,0939048 | 1,755518859 | 212,4195604 | 219,7682491 |
| Tension (MPa) | 4,672457576 | 0,096638133 | 4,470191577 | 4,874723575 |

Table III - Values of the analysis of regression for reliable interval for the data of the RMB for the method of Entropy of sample AISI 1045.

| | Coefficients | Error Standard | 95% Inferiors | 95% Superiors |
|---|---|---|---|---|
| Intersection | 52,22385714 | 0,704448952 | 50,74942808 | 53,6982862 |
| Tension (MPa) | 0,573035065 | 0,038778639 | 0,491870416 | 0,654199713 |

Table IV - Values of the analysis of regression for reliable interval for the data of the RMB for the method of Entropy of sample SAC 50.

| | Coefficients | Error Standard | 95% Inferiors | 95% Superiors |
|---|---|---|---|---|
| Intersection | 198,4380952 | 0,609366003 | 197,1626771 | 199,7135133 |
| Tension (MPa) | 2,505324675 | 0,033544494 | 2,43511522 | 2,575534131 |

## 8. Conclusion

In this article is presented a strategy of analysis of the RMB using Transformed Wavelets associated to the statistical analysis, becomes possible the differentiation of samples of different materials.

Verifies in Tables II to IV that for interval reliable of 95%, not had overlapping of intervals of tension for steel in analysis, what characterizes statistically that the Barkhausen signals emitted by the three samples are different, probably for the chemical composition of each sample.

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