THE USE OF MAGNETIC BARKHAUSEN NOISE ANALYSIS FOR MECHANICAL STRESSES EVALUATION

Silvério Ferreira da Silva Júnior
Centro de Desenvolvimento da Tecnologia Nuclear – CDTN/CNEN – CP 941 – CEP 30123-970 – Belo Horizonte, MG, Brasil.
silvasf@cdtn.br

Miguel Mattar Neto
Instituto de Pesquisas Energéticas e Nucleares – IPEN/CNEN – CP 11049 – CEP 05422-970 – São Paulo – SP – Brasil.
mmattar@ipen.br

Júlio Ricardo Barreto Cruz
Distrito de Fortaleza – DIFOR/CNEN – Av. Antônio Sales, 1418 – CEP 60135-101 – Fortaleza – CE – Brasil.
jcruz@cnen.gov.br

Abstract. *During its operational life, structural components are submitted to the influence of different failure-inducing agents, such as temperature and reactive environment. The combined action of these agents allied to the presence of residual stresses and applied stresses have a great influence on the components life and in-service behavior. Important information used for structural integrity evaluation of a particular component is the real stress state present in it. The possibility to determine the value of the stresses acting in the component by means of a nondestructive testing method presents an important feature because it does not introduce any changes into the material tested. The electromagnetic testing method based on the Barkhausen noise analysis presents advantages such as the possibility to perform stress measurements at high temperatures. This paper presents a study about the use of the Barkhausen noise analysis as a non-destructive testing method for determining the stress state in ferromagnetic materials. The experiments were carried out in ASTM A-515, ASTM A-36 and USI SAC 50 steels, used for pressure vessels and structural components manufacturing. The results obtained have showed a good sensitivity of this test method to stress changes. The main restrictions and applications of this testing method are discussed.*

Keywords*: Barkhausen noise, stress, non-destructive testing, magnetoelastic method*

1. Introduction

An important feature in the structural integrity evaluation of components is the knowledge of the stress state present in it.

For residual stresses measurements, several methods are currently used, each of them presenting advantages and restrictions. The methods used for this purpose are classified as destructive, semi-destructive and non-destructive methods. Examples of destructive methods are the ring core method, the layer removal method and the sectioning methods. Examples of non-destructive methods are the ultrasonic testing, x-ray and neutron diffraction testing and the magnetic methods. The Hole–Drilling Method, one of the most used for this purpose, can be considered as a destructive or a non-destructive method, depending on the final use of the tested component.

For applied stresses determination, it means, the stresses generated by the service loadings or the operational conditions, the experimental stress determination is usually done using electric strain gages. The component is instrumented using resistive strain gages and from the strains measurements performed during loading testing, hydrostatic testing or in-service operation, the principal stresses can be determined at the more critical regions. Although efficient, the use of this method presents some inconveniences. To assure the reliability of the results, the surface of the component should be submitted to a mechanical and chemical conditioning at the areas of interest, in order to allow the correct fixation of the strain gages. Depending on the accessibility of the component, the conditioning of the surface may be very difficult and a reasonable time can be expended to carry out these procedures, sometimes implying in an extremely high cost for its accomplishment. Additionally, in those situations where the equipment operation temperature is elevated, the use of special strain gages and procedures can make unfeasible the accomplishment of the test.

Magnetic methods have been studied as potential methods for stresses determination in ferromagnetic materials, as the magnetoelastic testing method, based on the magnetic Barkhausen noise analysis. Barkhausen effect originates from the interactions occurring between magnetic domain walls and pinning sites present into a ferromagnetic material during the magnetization process (Dhar, 1992). Magnetic domains are small areas present into a ferromagnetic material. In these areas, the magnetization value is equal to the saturation magnetization value for the material. They are randomly oriented into the material in the demagnetized state. Under influence of an increasing magnetic field, the domains aligned in the directions close to the magnetic field direction tend to increase and those aligned in less favorable directions tend to disappear. This process occurs during domain walls motion through the material.

Magnetic domain walls motion is affected by the presence of structural discontinuities such as precipitates, inclusions, grain boundaries and mechanical stresses (residual or applied stresses). They act as energy barriers to the domain walls motion, which occurs in jumps, from one pinning site to another, as the magnetic field increases. This discontinuous motion promotes discontinuous changes in the magnetic flow, which can be detected by a coil positioned in the surface of the material. The sum of all electric pulses induced in the coil during the magnetization process is called Barkhausen noise (Sipahi, 1994).

The mechanical stresses influence the distribution of the domains and the dynamics of the domain walls motion through the magnetoalastic interaction (Devine, 1992). In materials with positive magnetoestriction the presence of compression stresses reduces the intensity of the Barkhausen noise, the opposite occurring with the presence of tension stresses. Besides the elastic stresses, material hardness and microstructure also have influence in the intensity and characteristics of the Barkhausen noise.

An important characteristic of the magnetic Barkhausen noise is the directional dependence. Depending on the direction of the magnetic field applied to excite the material, the resulting magnetic Barkhausen noise will present different values. This fact is due to the magnetocrystalline anisotropy, presented by the processed materials (Dhar, 1992) and should be considered when using this test method for stress measurements. The experiments described in this paper were carried out in ASTM A-36, ASTM A-515 and USI SAC 50 carbon steels, due their large applications.

2. Experimental methodology

2.1. Loading device

The RMS value of the magnetic Barkhausen noise, generated into the material during the magnetization process under different stress levels, was obtained using a special loading device, similar to those used for strain-gages performance determination. Two constant stress cantilever beams were machined from samples of the materials studied, submitted to a heat treatment for stress relief, instrumented with KFG-5-120-C1-11-KYOWA strain gage rosettes and installed in the loading device. The direction of the excitation magnetic field generated by the magnetoelastic probe was parallel to the beam axis. The experimental set-up can be observed in Fig. 1.

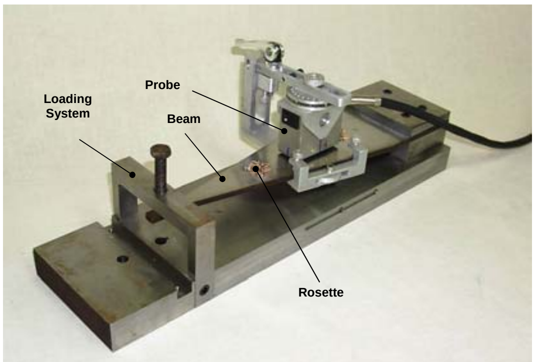

Figure 1. Experimental set-up used to obtain tension stresses (a) and compression stresses (b) at the beams surface.

2.2. Testing equipment

MBN measurements were performed using a Stresstest 20.04 unit and a magnetoelastic probe. The Stresstest 20.04 unit controls the test parameters (magnetic field excitation frequence and intensity and the data acquisition process during the measurements. The probe incorporates a yoke (to excite the material with a variable magnetic field) and a pick-up coil to detect the resulting magnetic Barkhausen noise. The material can be excited using a variable magnetic field with the frequency of 10 Hz and the resulting magnetic Barkhausen noise was detected using a 500 Hz filter.

The stress measurements during the experiments were performed with a KFG-5-120-C1-11-KYOWA strain gage rosette. The instrumentation for strain measurements includes an Agilent 4½ digit microvoltimeter and a 10-channel selector. The method of measurements was the direct measurement of the strain gage resistance, instead the conventional method using a Wheatstone bridge circuit. Measurements were performed at room temperature.

2.3. Stress sensitivity

To establish the dependence of the magnetic Barkhausen noise RMS value on the stress state changes occurring at the surface of the beams, different loads were applied in its extremity. The magnetoelastic probe positioned so that the direction of the excitation magnetic field stayed parallel to the longitudinal beam axes. This direction coincides with the direction of the maximum principal stress acting in the beam and the rolling direction of the material.

For each applied load (tension and compression), the value of the resulting stress was determined from the readings of the strains by the strain gages. At the same time, the RMS value of the resulting magnetic Barkhausen noise was registered. This procedure was done in order to cover the range between 90% of the yield limit in compression to 90% of the yield limit in tension, for the materials studied. The acquired data were used to obtaining the curves relating the RMS value of the magnetic Barkhausen noise as a function of the stress state in the materials.

2.4. Surface condition

The surface finishing o the material has great influence in the test results. Thus, the same procedure used to prepare the materials surface in the calibration steps should be used when testing real components. The dependence between surface condition and the value of the magnetic Barkhausen noise was determined from measurement of samples with different surface finishing.

2.5 Angular dependence

The changes in the RMS value of the magnetic Barkhausen noise as a function of the direction of the measurements was determined using the same experimental set-up shown in Fig. 2. For each material studied, the RMS value of the magnetic Barkhausen noise was measured in increments of 15°, in the same region, from 0° to 180°. In each position, the MBN was registered, allowing one to obtain the curves relating the amplitude of the MBN as a function of the direction of the measurements.

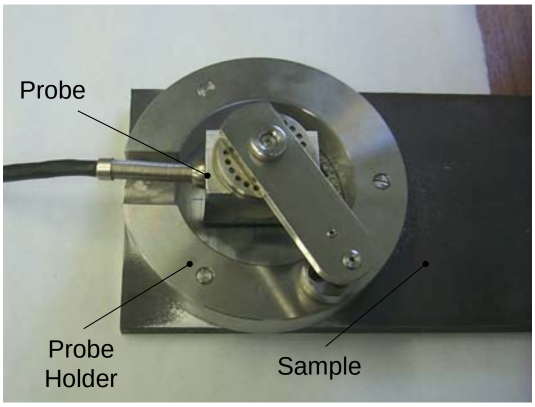

Figure 2. Experimental set-up used to verify the angular dependence of the MBN.

3. Experimental results

The changes occurring in the magnetic Barkhausen emissions with stress level, for the ASTM A-36, ASTM A-515 and USI SAC 50 carbon steels, can be observed in Figs. 3, 4 and 5. The results obtained for the dependence of the measurement direction and the influence of the surface finishing can be observed in Figs. 6, 7, 8 and 9.

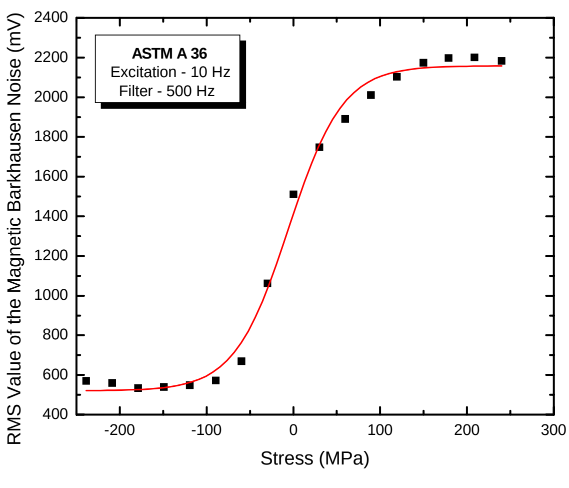

Figure 3. RMS value of the Magnetic Barkhausen noise as function of the stress value for ASTM A 36 Steel.

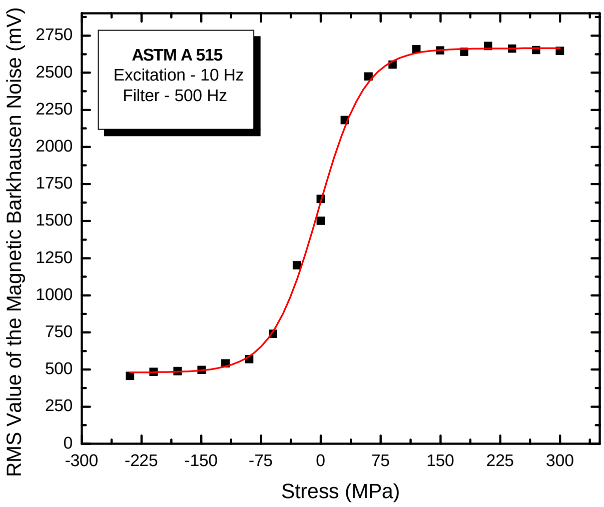

Figure 4. RMS value of the Magnetic Barkhausen noise as function of the stress value for ASTM A 515 Steel.

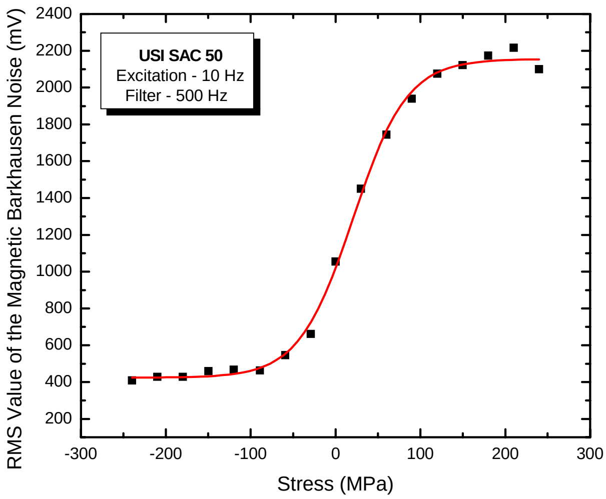

Figure 5. RMS value of the Magnetic Barkhausen noise as function of the stress value for USI SAC 50 Steel.

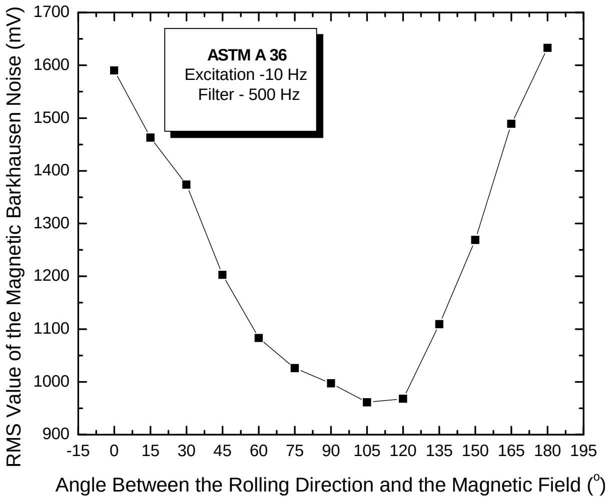

Figure 6. RMS value of the magnetic Barkhausen noise as function of the measurement direction for ASTM A 36 Steel.

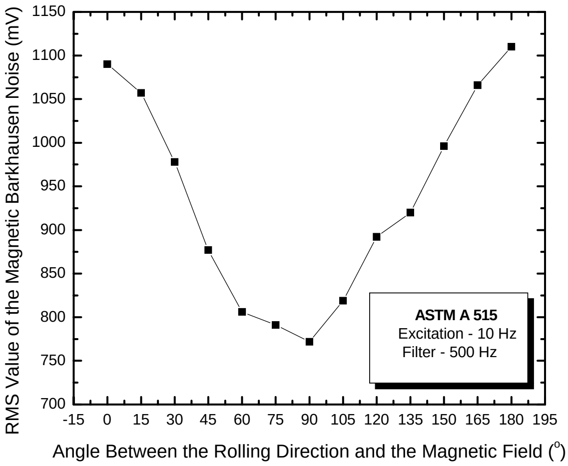

Figure 7. RMS value of the magnetic Barkhausen noise as function of the measurement direction for ASTM A 515 Steel.

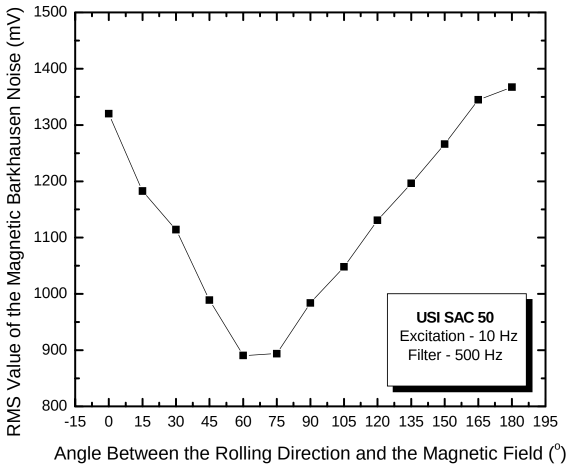

Figure 8. RMS value of the magnetic Barkhausen noise as function of the measurement direction for USI SAC 50 Steel.

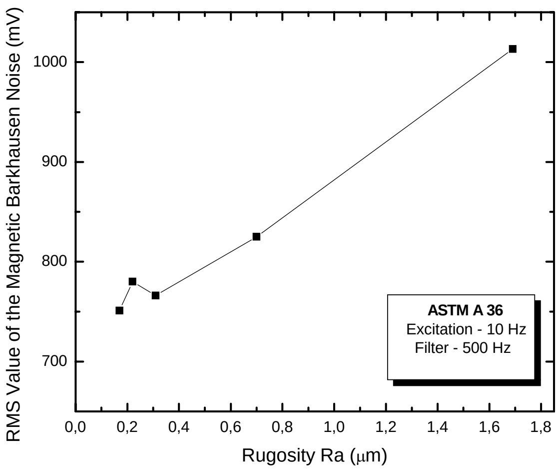

Figure 9. RMS value of the magnetic Barkhausen noise as function of the surface finishing for ASTM A 36 steel.

4. Results discussion

The curves relating the stress dependence of the magnetic Barkhausen noise for the materials studied can be observed in Figs. 3, 4 and 5. The results indicate a high sensitivity of this test method to stress changes, mainly for low stress levels. For high stress levels a saturation of the noise occurs. The region of the curves where the noise saturation occurs is dependent of the material. For ASTM A 36 steel the saturation occurs approximately at 120 MPa for compression stresses and at 200 MPa for tension stresses. For ASTM A 515 steel the saturation occurs approximately at 120 MPa for compression stresses and at 120 MPa for tension stresses. For USI SAC 50 steel these limits are 120 MPa and 200 MPa for compression and tension stresses respectively.

The curves obtained in Figs. 6, 7 and 8, representing the dependence of the RMS value of the measurements direction, indicate that the maximum and minimum value of MBN amplitude occurred in the directions approximately parallel and perpendicular to the rolling direction of these materials, respectively. This behavior is due to the magnetocrystalline anisotropy presented by these materials as consequence of the processing conditions during manufacturing (Dhar, 1992). The results obtained indicate the necessity to perform the measurements in defined regions in the material, the same used in the test system calibration. Usually, these directions are the parallel and perpendicular directions to the rolling direction of the material.

The surface finishing influence, shown in Fig. 9, indicates that when performing measurements using this test method, the surface finishing of the materials tested can be the same of the samples used in the test system calibration, in order to avoid errors in the measurements due to this factor.

5. Conclusions

Magnetic Barkhausen noise analysis can be applied for stress measurements in ferromagnetic structural materials. The range of the measurements depends on the material tested and should be determined from experimental data. The measurement direction and the surface finishing of the material tested have strong influence on the test results and should be controlled during the test system calibration and the measurements performed in the test specimen.

6. References

Devine, M. K., The magnetic Detection Material of Properties, JOM, p. 24-29, October 1992.

Dhar, A., Jagadish C., Atherton, D. L., “Using the Barkhausen Effect to determine the Easy Axis of Magnetization in Steels”, Materials Evaluation, October 1992, pp1139-1141.

Sipahi, L. B., Overview of Applications of Micromagnetic Barkhausen Emissions Material Noninvasive Characterization Technique, Journal of Applied Physics, v.75, n.10, p.6978-6980, May 1994.

7. Responsibility notice

The author(s) is (are) the only responsible for the printed material included in this paper.