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THE USE OF MAGNETIC BARKHAUSEN NOISE ANALYSIS FOR NONDESTRUCTIVE DETERMINATION OF STRESSES IN STRUCTURAL ELEMENTS

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ABSTRACT

The knowledge about the stress state acting in structural elements has significative importance in the structural integrity evaluation of a specific component. The magnetic Barkhausen noise analysis can be used for this purpose. As a nondestructive testing method, it presents the advantage of not promote any changes in the tested component. In this paper, a study about the use of this new nondestructive test method for stress measurements is presented. The test system configuration and the reference standards used for this purpose, as well as the optimum test parameters determination are discussed. The experiments were carried out in ASTM A-36 steel, used for structural components manufacturing. A structure of this material was loaded and the resulting stresses were determined from strain gage measurements and Barkhausen noise analysis. The results obtained have showed a good sensitivity of the magnetic Barkhausen noise to stress changes occurred in the material. The main advantages and limitations of this test method for stress measurements are presented.

1. INTRODUCTION

In many situations, the stress state present in a specific structural component must be experimentally determined, in order to allow the component performance during its operation. 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 or hydrostatic testing, the main stresses value and its direction can be determined at the more critical regions of the component. Although efficient, the strain gage technology presents some disadvantages. The components surface, in the regions where the strain gages will be fixed, must be submitted to a special preparation, involving steps such as its mechanical and chemical conditioning, Depending on the region of the component to be evaluated, the accessibility and the environment condition, these procedures can spend an excessive time, with the consequent increase in the cost for carry out the measurements. If the test needs to be performed at elevated temperatures, the use of specific strain gages and special test procedures can make unfeasible the accomplishment of the test.

In the last years, several nondestructive test methods have been studied for stresses determination purposes in structural materials. The most promising are the ultrasonic testing and some magnetic tests, such as the magnetostriction method and the magnetoelastic method based on the magnetic Barkhausen noise analysis [1].

Barkhausen effect originates from the interactions occurring between magnetic domain walls and pinning sites present into a ferromagnetic material during the magnetization process [2].

Magnetic domains are small areas existing into a ferromagnetic material where the magnetization value is equal to the saturation magnetization value for the material. 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 is called domain walls motion and it is affected by the presence of structural discontinuities into the material, such as precipitates, inclusions, grain boundaries and mechanical stresses (residual or applied stresses). These discontinuities 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 flux, which can be detected by a coil placed on the materials surface. The sum of all electric pulses induced in the coil during the magnetization process is called Barkhausen noise [3].

The distribution of the domains and the dynamics of the domain walls motion are influenced by the presence of mechanical stresses, through the magnetoelastic interaction [4]. For materials with positive magnetostriction, the intensity of the magnetic Barkhausen noise decreases as the compression stresses applied to the material increases. The opposite occurs for tension stresses. To use the magnetic Barkhausen noise analysis for stress determination in ferromagnetic materials it is necessary to perform a carefully calibration of the test system. This procedure consists in to apply, under controlled conditions, different loads in a specimen of the material to be tested and monitoring the resulting magnetic Barkhausen noise due to each load condition. After that, a calibration curve can be obtained, relating the magnetic Barkhausen noise RMS value with the stresses state present in the tested material.

2. METHODOLOGY

2.1. Materials

The material used in this study was the ASTM A-36 steel, due to its importance as a structural material. However, the procedures introduced here can be applied to other ferromagnetic materials. Tension tests performed in samples of this material, according ASTM E 8M-96 shown a yield strength of 290 MPa. The calibration test specimens and the structure used in the experiment were manufactured from a 1000mm x 1000 mm x 6,35 mm plate of the material studied. The material's surface, at the places selected to fix the strain-gages and the rosettes, were prepared according to the conventional techniques of strain gage technology.

2.2. Calibration Test Specimens

The test system calibration was performed using a constant stress cantilever beam as a calibration test specimen. The beam was manufactured with its longitudinal axis parallel to the rolling direction of the ASTM A 36 steel plate and submitted to a heat treatment for stress relief. After that, it was instrumented with a three element rosette KFG-5-120-C1-11-KYOWA. Instrumented beams such as the used in this experiment can be observed in Fig. 1(a). A micrography showing the microstructue of the material studied can be observed in Fig. 1(b).


(a) (b)

Figure 1. Instrumented constant stress cantilever beam (a) and microstructure of the ASTM A 36 steel plate used in the experiment.

2.3. Test Specimen for Stresses Measurement

The test specimen used for stresses measurements can be observed in Fig. 2. It was designed with a truss shape, in order to allow the generation of uniaxial stresses tension or compression) in its elements during loading test. This test specimen was instrumented with a three element rosette KFG-5-120-C1-11-KYOWA, the same used in the constant stress cantilever beam.

2.4 Equipment

Magnetic Barkhausen Noise measurements were carried out using a Stresstest 20.04 unit and a 144221 general use probe. The probe incorporates a yoke, to exciting the material with a variable magnetic field and a pick-up coil to detect the corresponding magnetic Barkhausen noise.

The electromagnetic probe was feed with a 1570 mA excitation current at a 100 Hz frequency. The magnetic Barkhausen noise was acquired using electronic filters with frequencies of 500 Hz, 2 kHz, 8 kHz and 32 kHz. The Stresstest 20.04 unit and the electromagnetic probe can be observed in Fig. 3.The value of 1570 mA for probe excitation was experimentally determined.

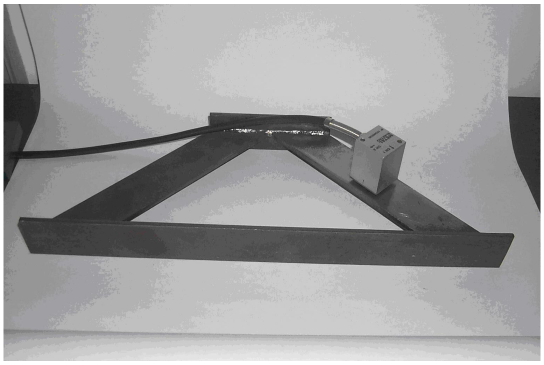
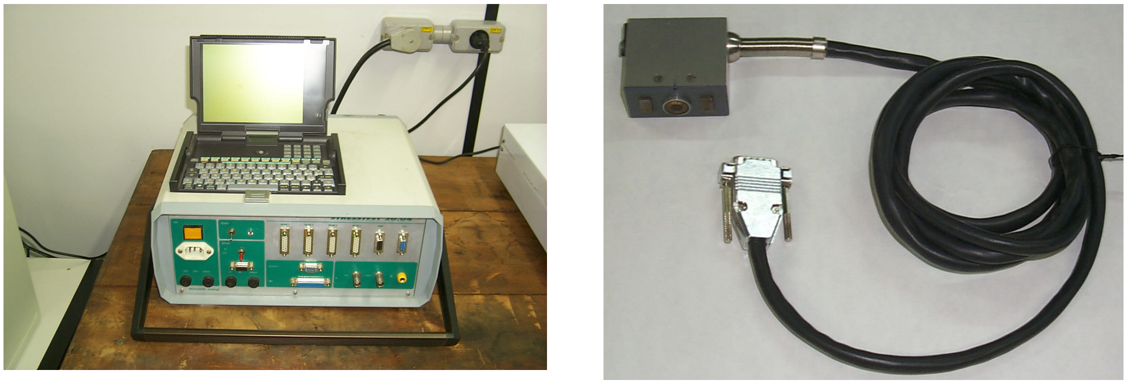


Figure 2. Instrumented test specimen used for stresses measurement.



(a) (b)

Figure 3. Stresstest 20.04 unit (a) and the electromagnetic probe used in the experiments (b).

2.5 Experimental Set-up

2.5.1 Calibration

During the calibration stage, a series of loads is applied to the constant stress beam, At each loading level the value of the stress at the beam's surface is determined from the KFG-5-120-C1-11-KYOWA rosette measurements. At same time, the magnetic Barkhausen noise generated in the material is acquired and its RMS value determined. The loads used during the calibration stage are selected in order to generate stresses at the beam's surface in the range from 80% of the compression stress yield to 80% of the tension stress yield. After that, a calibration curve relating the RMS value of the magnetic Barkhausen noise and the corresponding values of the stresses in the calibration specimen surface can be obtained, allowing performing stress determination in components of the same material. This determination is accomplished comparing the RMS value of the magnetic Barkhausen noise generated in the component's surface and those of the calibration curve. The calibration procedure adopted in this experiment can be used when the main stresses acting in the material are normal stresses. The experimental set-up fpr test system calibration can be observed in Fig. 4.

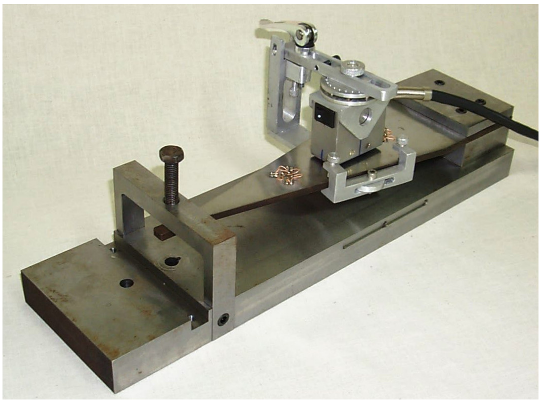


Figure 4. Experimental Set-up for test system calibration.

2.5.2 Test specimen loading

After the test system calibration, the test specimen was positioned in a manual hydraulic press, as can be observed in Fig. 5. Loads were applied to the test specimen in order to generate tension stresses in the horizontal element. During each loading step, the stresses present in the horizontal element were determined from strains measurements performed by the KFG-5-120-C1-11-KYOWA rosette. At the same time, the RMS value of the magnetic Barkhausen was acquired.

Figure 5. Experimental Set-up for test specimen loading.

2.6 Test Results

2.6.1 Calibration Curve

The calibration curve can be observed in Fig. 6.

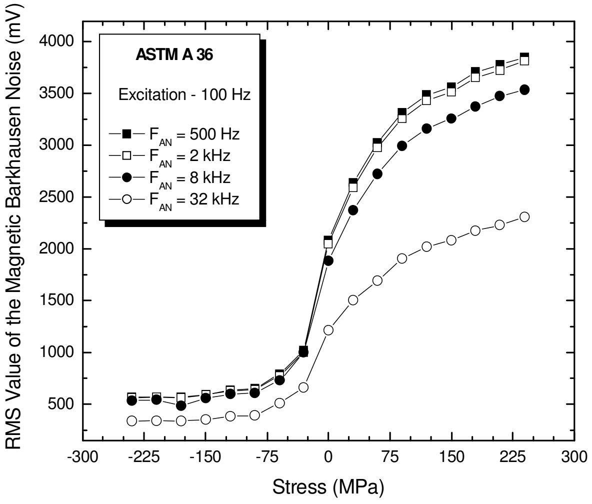


Figure 6. Calibration curve for ASTM A 36 steel.

2.6.2 Stresses measurements

The results obtained from magnetic Barkhausen noise analysis and strain gage measurements can be observed in Fig. 7.

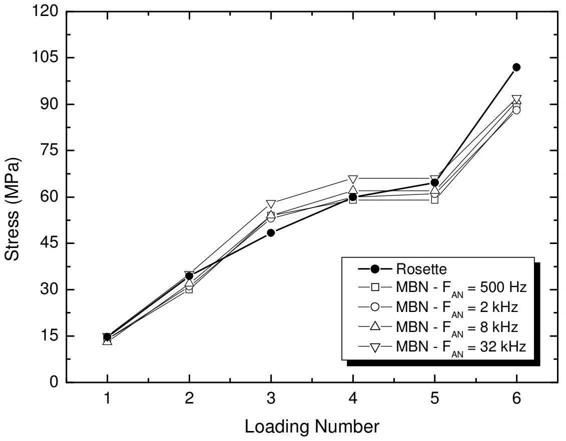


Figure 7. Results of the stress measurements performed with a strain gage rosette and the magnetic Barkhausen noise analysis.

3. CONCLUSIONS

A good sensitivity of the magnetic Barkhausen noise RMS value to the stress changes occurred in the tested material was observed. A good correlation between the stresses values determined by the magnetic Barkhausen noise analysis and the strain gage rosette was observed too. This behavior was observed for all analysis frequencies used during the acquisition of the magnetic Barkhausen noise (500 Hz, 2 kHz, 8 kHz and 32 kHz). These results suggest the applicability of this test method for stress measurements in the stress range adopted in this experiment.

For high stresses levels, near the yield limit of the tested material, a saturation of the magnetic Barkhausen noise occurs, as can be observed in Fig. 6. This fact suggests a limitation in the use of this test method for stress measurements purposes.

The experimental set-up used in the experiments was adequate, allowing a correct determination of the stresses levels acting in the test specimen, under the presence of uniaxial stresses.

The next stage of this work involves experiments with other structural ferromagnetic materials, used in nuclear and conventional industries, in order to obtain a set of data that allows establishing a general behavior of the test method based on the magnetic Barkhausen noise analysis for stresses determination in ferromagnetic materials.

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