Magnetic Barkhausen Noise Surface Map for non-destructive inspection in structural steels with plastic deformations

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Abstract. *A36 structural steels are inspected for non-uniform plastic deformations employing 2D and 3D Magnetic Barkhausen Noise Surface Maps. It has been found that the RMS voltage of the Magnetic Barkhausen Noise decreases with plastic deformations for 540 – 760 Mpa. The results show that the 2D and 3D Magnetic Barkhausen Noise Surface Maps are a good alternative for non-destructive inspection of deformed commercial steels.*

***Keywords*:** Magnetic Barkhausen Noise, Plastic Deformation, Structural Steels

1. INTRODUCTION

The Magnetic Barkhausen Noise (MBN) method for non-destructive evaluation of metallurgical properties of ferromagnetic materials has been used for more than 30 years. This MBN application is based on the fact that variables such as microstructure (Saquet et all, 1999; Kameda, 1987; Kameda, 1987b), crystallographic phases [Kameda, 1987; Kameda, 1987b; Bussiera, 1986; Alpeter, 1996) and chemical composition (Saquet, 1999; Alpeter, 1996; Moorthy et al, 1997; Goodenough, 1954; Habermehl et all, 1985), which determine the physical properties of materials, also affect their magnetic characteristics. On the other hand, more recently, the MBN method for assessing materials properties using some parameters, such as grain size [Moorthy et all, 1997; Anglada-Rivera, 2001; Gatelier-Rothea, 1998), applied stress (Saquet et all, 1999; Anglada-Rivera, 2001; Hwang, 1987), carbon content (Ng et al, 2002, Koo et al, 2003) or plastic deformation (Libgreen, 2003; Dhar et al, 2001; Iordache et al, 2003), are also receiving increasing attention. Due to the wide range of applications and their diversity, it is natural to divide the field of MBN applications into two classes: one concerning defect detection and characterization and other concerning material property measurements.

The first class of applications has not been widely reported in commercial steels yet. Nevertheless it is worth to mention the work of Krause (Krause et al, 1997) which establishes the correlation between MBN and Magnetic Flux Leakage (MFL). The MFL is a technique presenting one of the smallest cost/benefit rate concerning in line inspection of pipelines for metal loss defects (Mandal, 1998), such as corrosion pit. The effect of the stress on the flux leakage maps is of considerable importance since gas or oil pipelines can be inspected while they are in operation.

The present paper is primarily concerned with the first class of MBN applications. A novel method is presented for studies of plastic deformations in structural steels, associated with the analysis of their Magnetic Barkhausen Surface Maps. Up to present, there were no reports discussing this non-destructive testing technique.

2. EXPERIMENTAL PROCEDURE

2.1 Materials.

Identical parallelepiped samples (long = 200 mm, wide = 25 mm, thick = 2,5 mm) were prepared from A36 structural steel. Chemical composition, heat treatments, and mechanical properties of investigated steels are summarized in table 1. In order to avoid surface residual stress, all machining operations on these samples were performed prior to heat treatments. The high temperature treatment was performed in Argon atmosphere, which avoids surface oxidation and decarburization.

Before the magnetic measurement process, samples were deformed transversely to the rolling direction, using a hydraulic compress machine (Schiwing Siwa). All tests were carried out in the interval of 600 – 760 Mpa of applied stress (within the zone of plastic deformation).

Table 1. Chemical composition, heat treatment, and mechanical properties of structural steel.

Chemical Composition (wt %)	Heat Treatment	Predominant Microstructure	Mechanical Properties	
			Allowable Bearing Stress (MPa)	Allowable Tensile Stress (MPa)
C - 0.20 Mn - 0.55 P - 0.012 S - 0.037 Si - 0.007 Cu - 0.01 O - 0.079 N – 0.0032	925 ^{0}C, 10 min., air	Ferrite fine grain (~ 20 μm)	~ 600	~ 200

2.2 Experimental Device.

The experimental device enabling in situ magnetic measurements is presented in Fig. 1. An alternating magnetic field *H* with a frequency of 1 Hz was applied to samples using a ferrite yoke (25 x 25 mm^2 section). The magnetic field was driven by a sinusoidal waveform generator (Tektronic CGF 253) with output amplified by a bipolar power supply (Kepco BOP20-20D). The sinusoidal waveform amplitudes were equals to ± 1 A, generating a magnetic field of ± 2.5 x 10^5 A/m, which is sufficient to produce magnetic sample saturation. A Hall sensor measures this magnetic field at the specimen surface. A commercial magnetic head, placed on the sample surface, detects the MBN signals induced by the domain wall motions. The MBN sensor output is connected to a preamplifier of 2000 gain and to a band pass filter (4-100KHz). A data acquisition system records MBN measurements.

In order to obtain MBN surface maps of samples (~ 1 mm^2 resolution), the movement of the MBN sensor was driven using a commercial steep motor interfaced with a personal computer. An area of w = 25 mm x l = 50 mm, around a circular deformed zone of about 15 mm diameter, was scanned by the MBN sensor.

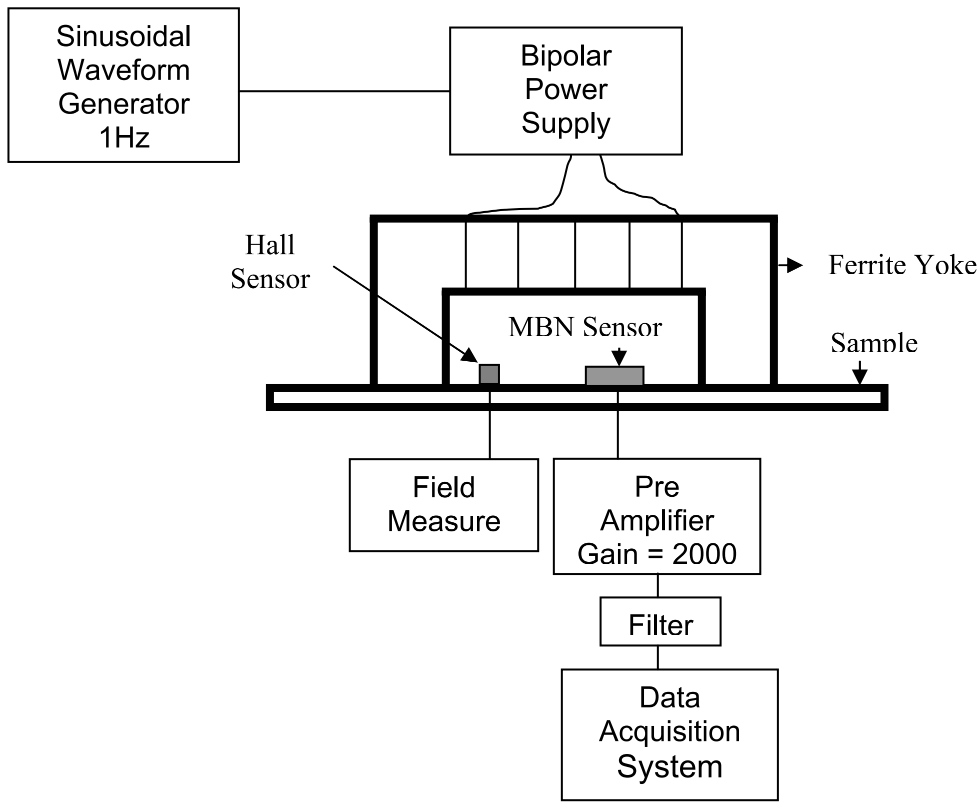

Figure 1. Schematic diagram of experimental device

3. RESULTS AND DISCUSSION

The RMS voltage (Vrms) of MBN signals of non-deformed and previous plastic deformed samples for different applied stress was measured.

Before a detailed comparison of the non-deformed and previous deformed samples the general features of 2D and 3D MBN surface map are examined. Figures 2(a) and 3(a) show 2D and 3D MBN Vrms surface maps in the absence of any applied stress. It its clear from these figures that for zero applied stress, the MBN Vrms values change very little in the scanned area. These changes are associated with surface and macrostructures irregularities.

Figure 2(b) and 3(b) show a typical variation of 2D and 3D MBN Vrms surface maps for deformed samples (760 Mpa applied stress). The MBN Vrms values decrease in the deformed zone and a considerable change in real MBN signals takes place in this zone as shown in fig 4(a) and (b).

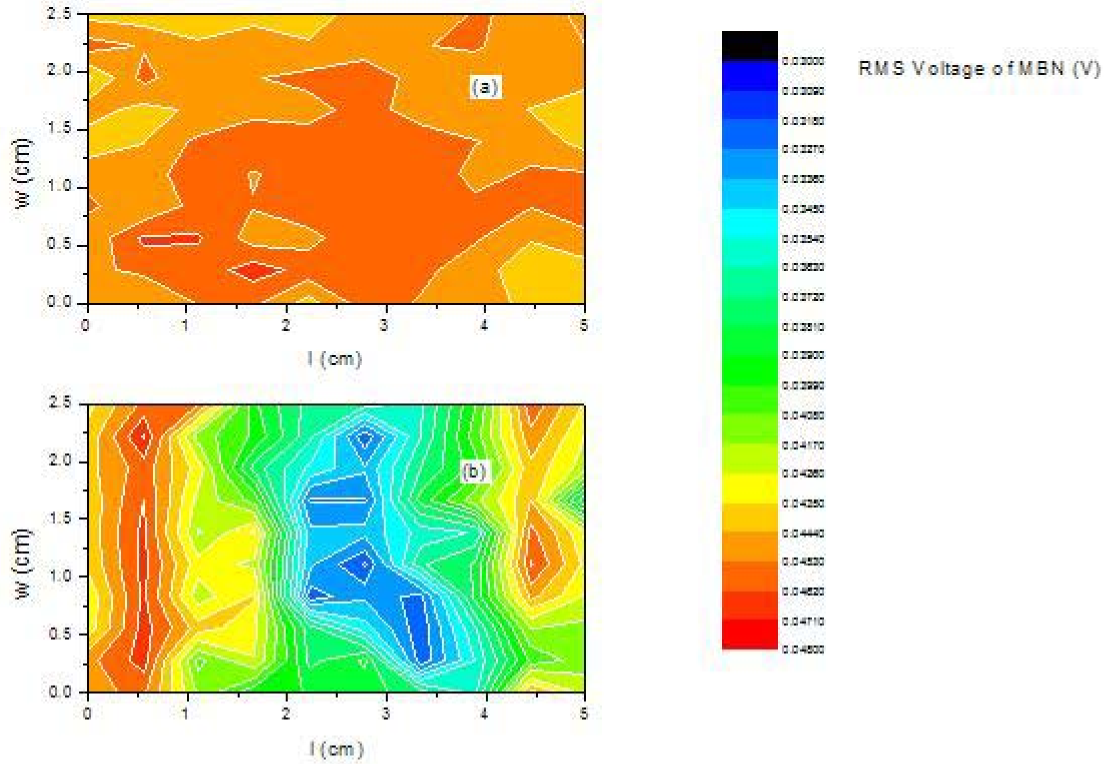

Figure 2. 2D Color MBN Surface Map of A36 structural steels: (a) non-deformed sample, (b) deformed sample.

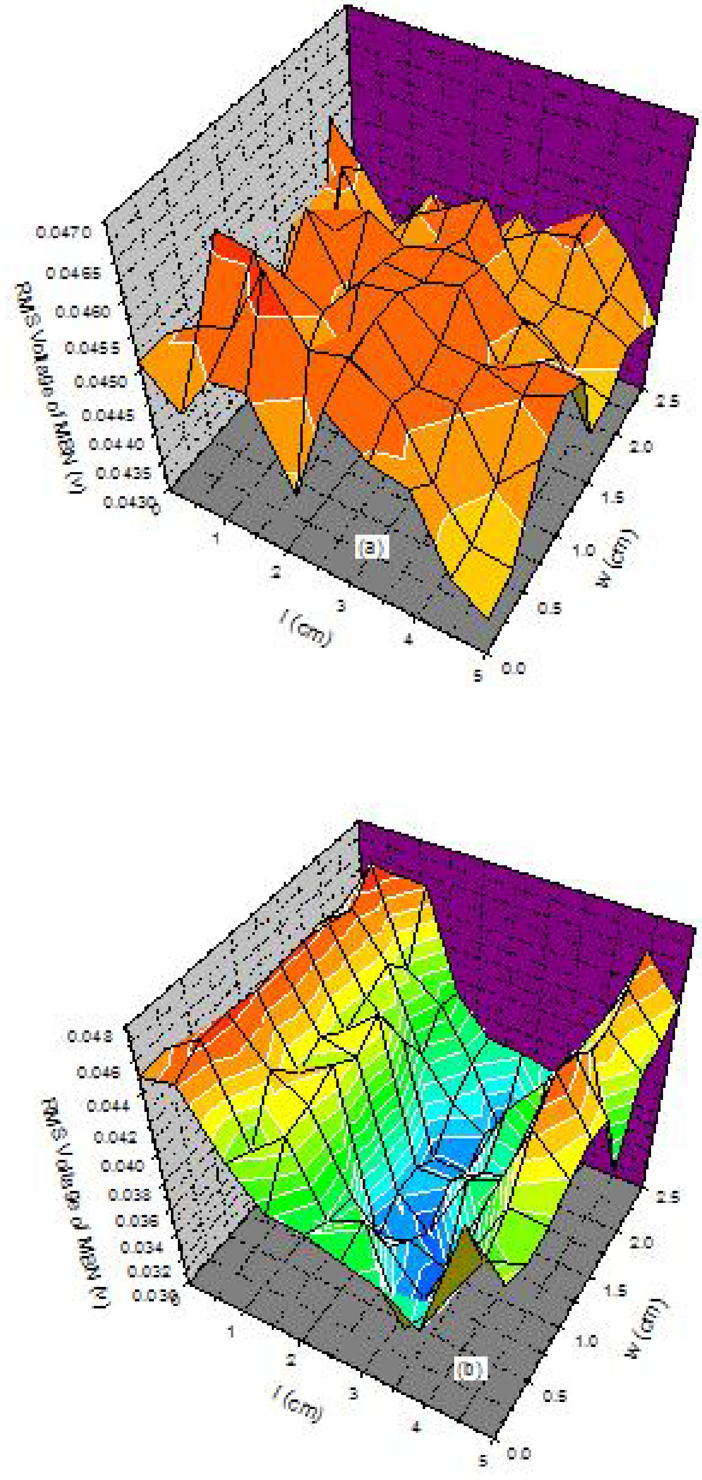

Figure 3. 3D Color MBN Surface Map of A36 structural steel: (a) non-deformed sample, (b) deformed Sample.

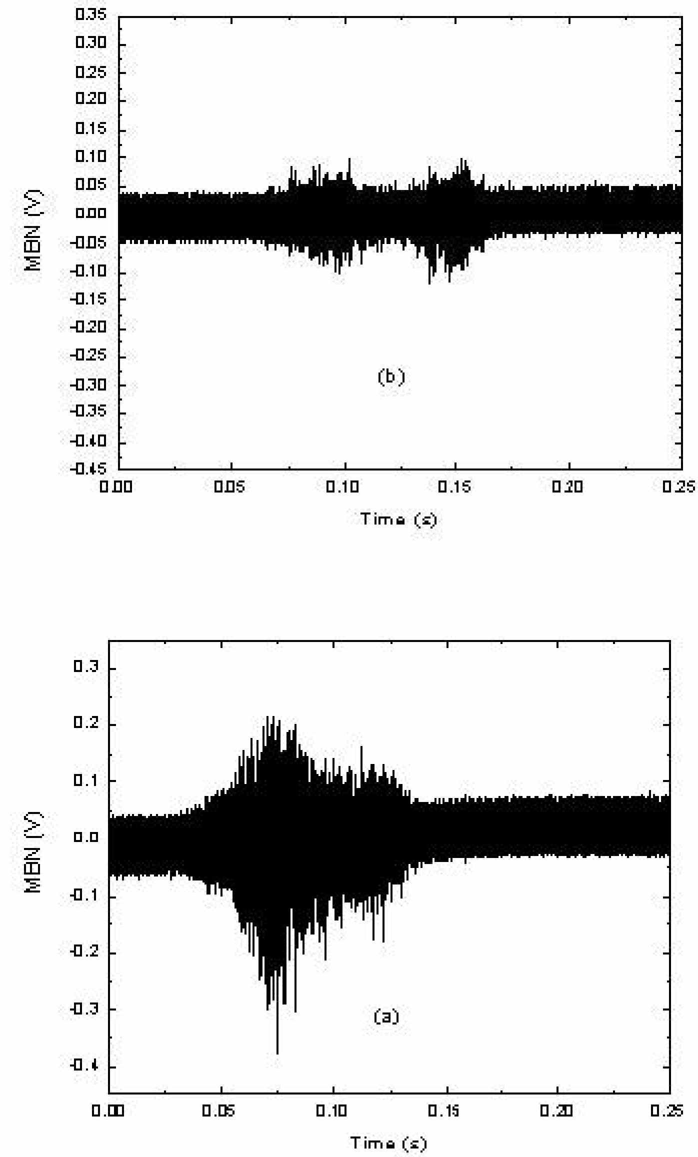

Figure 4. Example of the MBN signals for different zone of samples: (a) non-deformed zone, (b) deformed zone (760 MPa).

As it is known (Cullity, 1972) , steel plates are manufactured by rolling. This process induces a macroscopic easy axis of magnetization in the structural steel plate. This axis has the crystallographic direction <100> which is the same of the rolling direction.

Application of compression stresses perpendicular to the steel samples axis direction induces a magnetic anisotropy energy perpendicular to the steel samples axis main direction and shifts the direction of the magnetic easy axis from the plate axis to the circumferential direction.

On the other hand, the deformation produces an increase in the defect density which makes more difficult the magnetic domain wall motion. Hence, a significant decrease of the magnetic energy of the system, and consequently, the decrease in MBN activity occur. This explains the decrease of MBN Vrms value (in the zone of plastic deformation) with increasing applied compression stress, seen in Fig. 5, which agrees with experiments reported for other plain steels [Mandal, 1998; Saquet et al, 1999; Hwang, 1987; Cullity, 1972).

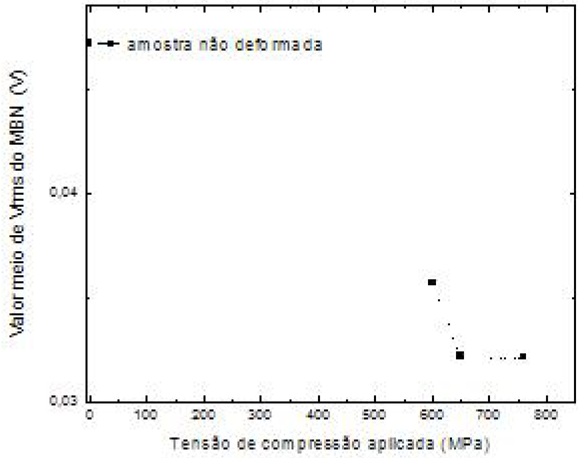

Figure 5. Effect of the applied compression stress on the average MBN Vrms in A36 structural steel.

The deformation gradient in samples is reflected in Fig. 2 (b) and 3 (b), indicating that mechanical deformation has a rather drastic effect on the MBN generated by the magnetic domain wall motion. Since the MBN Vrms variations between nominally identical samples are much larger than those seen in repeated measurements of the same sample, it is reasonable to conclude that samples prepared under identical conditions are, really, not identical. This is related with the fact that steels are complex composite materials. Nevertheless, as was observed in these experimental results, the differences in the MBN Vrms surface maps generated by samples with different plastic deformation are much greater than the differences observed between those produced by samples with nominally identical plastic deformation.

4. CONCLUSIONS

This experimental work reveals that it is possible to distinguish plastic deformed zones in structural steels employing MBN Vrms surface map. The MBN Vrms values strongly decrease with applied compression stresses in zones of plastic deformation of samples.

Although the information about plastic deformation of commercial steels can often be determined via other methods, such as X-ray diffraction, and Scanning SQUID (Superconducting Quantum Interference Device) Microscope, the use of the MBN surface map offers a simple, fast and cheap technique for non-destructive evaluation of structural steels.

5. ACKNOWLEDGEMENTS

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