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EVALUATING OF STRESSES IN WELDED STRUCTURES BY MEANS OF REVERSE MAGNETIZATION METHOD

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Abstract: *Systems and methods of in-service inspection have become of great importance nowadays due to the need of evaluating of the service resource of structures, including welded ones. Their fitness for purpose during service life depends not only on imperfections and stresses caused by welding itself but on stressed state's changes in process of operation as well. Magnetic method of in-service NDT of welded pipelines is described. Its main difference from other known magnetic-based NDT methods being using the alternating current for sensor feeding. Experiment details, data analysis and comparison with those obtained by the widely used coercive force method are presented as well. It was shown that results obtained by proposed method are rather close to other ones, but the method itself allows the inspection to be performed more quickly and in a more effective way.*

Keywords*: mode of deformation, non-destructive testing, technical diagnostics, metallic structure life, reverse magnetization parameters.*

1. INTRODUCTION

The main purpose of technical diagnostics is to evaluate main factors affecting structure's operability: mechanical properties of material, different kinds of imperfections, current mechanical stresses and deformations, etc. The first two factors are relatively easy to determine – there are a lot of high accuracy methods, while mode of deformation still remains the least technically completed and mathematically assisted.

Magnetoelastic method is successfully used for monitoring of stresses in metallic structures (Fomichov et al., 2012), but it doesn't work for plastic deformations. Magnetic memory method is used to spot zones with anomalies in self-fields of dissipation with further interpretation of these zones as stress concentrators (Dubov et al., 2006). The method doesn't give any information about values of stresses and deformations themselves. Magnetic noise method cannot be used in case of biaxial stresses when signs of normal components aren't pre-determined (Vengrinovich and. Dmytrovich, 2008).

Coercive force method is the most applicable for evaluation of plastic deformations and stresses (Muzhytskyi, 2001 and Bakharev, 2004). It is sensitive to metal structure and can be used to characterize degradation of material properties.

Among the factors which limit application of this method is the fact that it works in constant magnetic fields. The structure is being magnetized up to saturation and the sensor 'freezes' on its surface. In comparison to other methods mentioned, measuring time – during which the sensor remains immovable – is significantly increased. High power inputs are another disadvantage of this method.

Authors believe that application of AC for structure magnetizing and application of fields which don't lead to structure saturation is a key to removal of the disadvantages described. Such method, for instance, will allow structure scan with purpose of spotting the zones with highest loads.

Objective of this research was to evaluate the possibility of application of magnetic method with AC magnetizing without structure saturation for evaluation of stresses in the structure.

2. RESEARCH DETAILS

Experiments were performed for samples 4 and 8 mm thick made of 09G2S steel (<0.12 % C, 0.50 – 0.80 % Si, 1.30 – 1.70 % Mn). The samples were loaded with uniaxial tensile stresses up to 140 MPa by means of pure bending (yield strength of 09G2S steel is 265 MPa – 345 MPa).

Experimental equipment included AC generator, amplifier, converter, A to D converter (ADC) and industrial computer. Converter was designed as П-shaped magnetic core with magnetizing and measuring windings with contact spot size 30 mm x 17 mm. Signal recording (currents in magnetizing and measuring windings) was performed using ADC NI USB-6009 with sampling frequency 10 kHz. For such converter design the current in magnetizing winding is proportional to magnetic field intensity and the current in measuring winding – to first derivative of magnetic inductance. The signals obtained from measuring winding were integrated by Simpson's method.

Magnetizing of samples was performed in alternating field with magnetizing force 300 A/m; 17.5 V; 50 Hz sinusoidal voltage was applied to magnetizing winding. To compare the developed method with coercive force method measurements on the same samples were performed with "KIM-2M" industrial device.

Similar to coercive force method magnetizing force H when B = 0 T was chosen as informative parameter. It was determined in each experiment from hysteresis loop (Fig. (1)). Magnetizing force depends on current in converter's magnetizing winding, which, in turn, depends not only on parameters of the power source, but also on magnetic conductivity of the sample material. This conductivity depends on stresses and deformations in sample. This led to varying of magnetizing force for different experiment conditions. To unify the results for all experiments (for the purpose of further comparison of results) the measured value of H was normalized by dividing by Hmax.

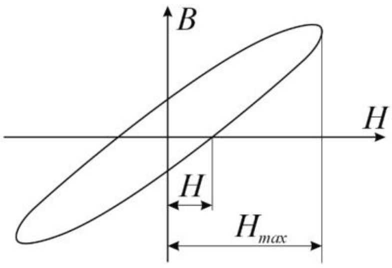

Figure 1: Example of hysteresis loop and magnetizing parameters.

Measurements on each sample were performed for two cases: converter positioned along and transversely to stresses because magnetic conductivity of the material varies in different way in these directions.

3. RESULTS OF EXPERIMENTS

During experiments we've obtained a number of $H/H_{max}\big|_{B=0}$ values depending from stresses in the sample for two cases of converter positioning: along and transversely to stresses (Fig. (2)). Data analysis has shown that these characteristics are linear related. It should also be mentioned that $H/H_{max}\big|_{B=0}$ when converter is positioned transversely to stresses grows faster with stresses increase than when it is positioned in longitudinal direction.

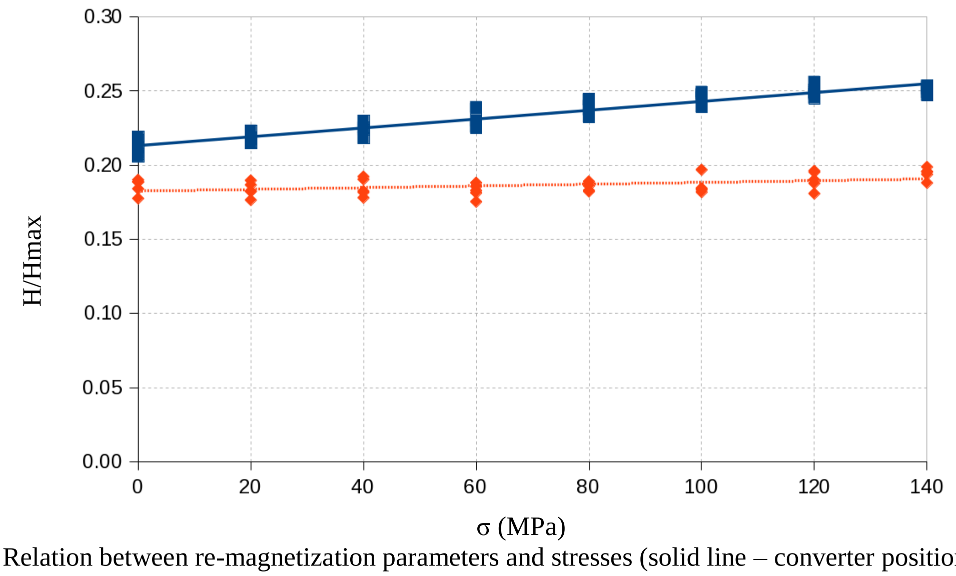

Figure 2: Relation between re-magnetization parameters and stresses (solid line – converter positioned transversely to the stresses, dashed line – converter positioned along the stresses).

The data obtained were approximated to linear subjection $y = a \cdot x + b$. Coefficient of determination R^2 value was 0.9 for the case when converter was positioned transversely to stresses. This means that approximation has a rather high precision and can be used in further calculations. The function obtained is as follows Eq. (1).

$$H/H_{max}\big|_{B=0} = 0.0003 \cdot \sigma + 0.21329 \quad (1)$$

For the case when converter was positioned along the stresses R2 value was 0.21. A conclusion can be done that when converter is positioned along the stresses it is very difficult to evaluate residual stresses in the sample. This conclusion is in full accordance to other research results (Bakharev, 2004).

The same experiments were performed with measuring with industrial coercimeter "KIM-2M" (Fig. (3)). These results has shown that developed method of evaluation of stresses allows to obtain data which relate to stresses’ value similarly to coercive force method with slightly higher data correlation.

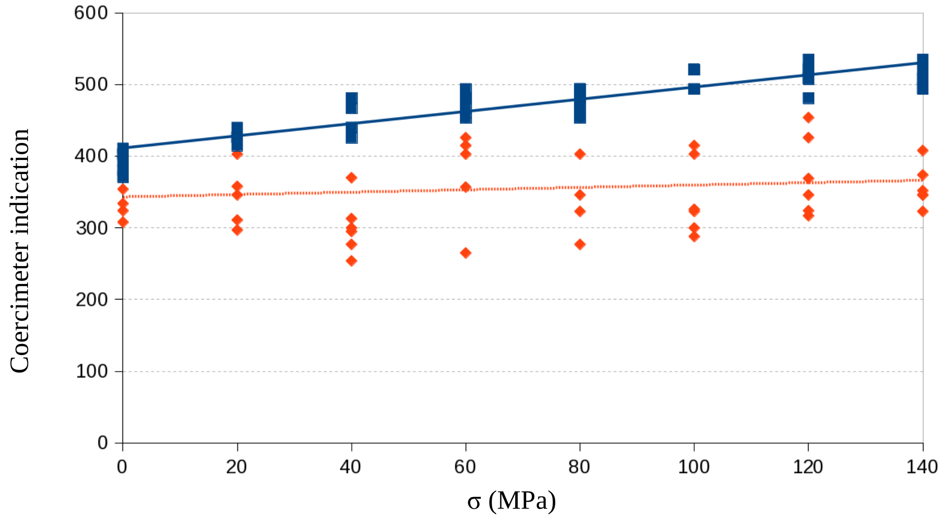

Figure 3: Relationship between measurement results performed by coercivemeter and stresses (solid line – converter positioned transversely to the stresses, dashed line – converter positioned along the stresses).

Additional experiments on the same samples were performed to define optimal magnetizing parameters. They were magnetized by alternating field with magnetic force 100, 200, 300 and 400 A/m. Similarly to previous experiments data approximation to linear functions was done. Then these functions were used to calculate stresses’ values and calculation results were compared to real ones. For each combination of stress value and magnetic force an error was calculated and averaged by 5 measurements (Fig. (4)).

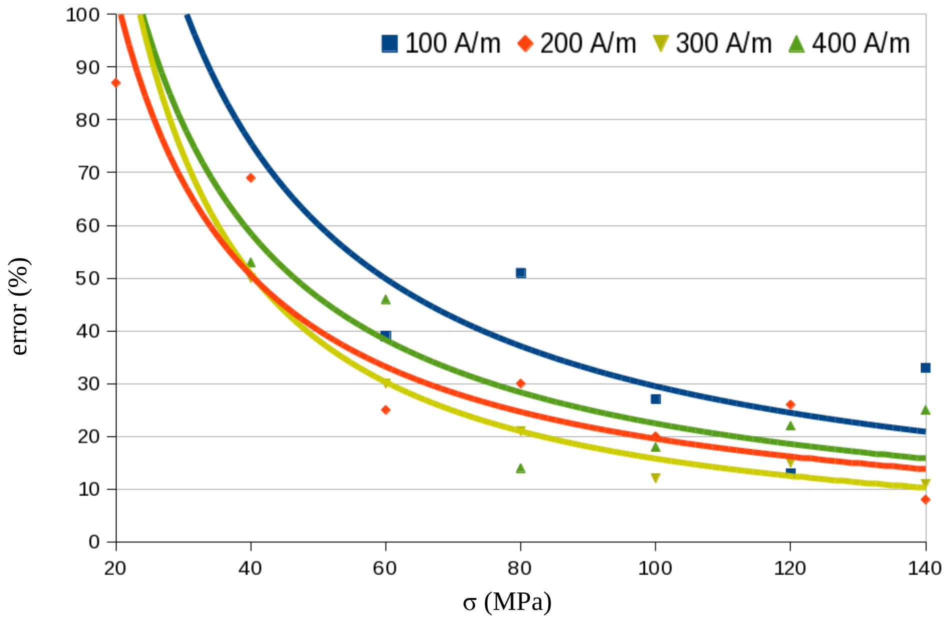

Figure. 4: Average relative error of stresses’ evaluation.

Analysis of data obtained has shown that when magnetic force increases up to 300 A/m relative error of stresses’ determination decreases. When magnetic force exceeds its value of 300 A/m the error starts to increase, meaning that the optimal magnetic force value should be chosen close to 300 A/m.

When stresses’ values exceed 100 MPa relative error (magnetic force 300 A/m) is lower than 20 %. In comparison to yield strength of most low-carbon construction steels this value is at least twice lower, which makes the developed method applicable for evaluation of residual stresses in welded structures and for spotting the most stressed zones.

4. CONCLUSIONS

Experiments have proven principal possibility of evaluation of stresses in welded structure by parameters of re-magnetization in low fields. Developed method allows to perform measurement in scanning mode: the structure material isn't saturated and sensor itself doesn't "freeze" on its surface.

As a result of experiments, data about relation between re-magnetization parameter $H / H_{max}|_{B=0}$ and stresses were obtained. It was shown that informative data can be obtained in case of converter being positioned transversely to stresses' direction. The function suitable for calculations was found which allows to define the re-magnetization parameter value by pre-defined stress value. Its coefficient of determination is 0.9. Positioning of converter along the stresses gives practically no useful information: relationship between parameters is very weak. These results match the same relationship obtained by coercive force method.

It was shown that average relative error of stresses' evaluation by re-magnetization parameters in low fields decreases with stresses' growth. When stresses' value exceeds 100 MPa the error is lower than 20 %. The method developed is applicable for evaluation of residual stresses in welded structure and spotting the most stressed zones in them.

It was determined that magnetic force value should be chosen close to 300 A/m. This parameter range allows to perform measurements with lowest possible relative error.

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