STRESS ASSESSMENT IN CONSTRUCTION STEEL ELEMENTS UTILISING MAGNETOELASTIC VILLARI EFFECT

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1. Introduction

The magnetoelastic effect in steel was reported for the first time by Villari in 1865 [1]. Since then, this effect is intensively investigated, both in a theoretical and application way. Magnetoelastic effect is important from theoretical point of view, because of the lack of quantitative, holistic model of interaction of mechanical and magnetic processes [2]. Such model would be very useful for development of novel, functional materials, such as amorphous [3] or nanocrystalline [4] magnetic materials. On the other hand, practical applications of magnetoelastic effect covers development of robust stress and force sensors [5] and stress assessment on the base of changes of magnetic properties of steel [6]. Among available methods of non-destructive testing, magnetic properties oriented methods have distinctive advantages. First of all, non-destructive, magnetic tests (based on magnetoelastic characteristics of the material) are contact-less, which simplifies the process of tested element surface preparation. In addition, magnetic field generation, in the range of energy and frequency used for non-destructive tests, doesn't create health risk for operator, which is significant advantage in comparison with the X-ray radiation based methods usage.

However, magnetoelastic characteristics oriented methods of non-destructive tests are not widely used in industry. The main barrier for such industrial application is the lack of knowledge about magnetoelastic characteristics of specific types of construction steels. This limitation is directly connected both with lack of robust, unified testing methodology of testing the magnetoelastic effect as well as quantitative description of stresses dependencies of magnetic parameters of different types of construction steels. This paper is trying to fill both of these gaps. It presents industrial application oriented methodology of magnetoelastic investigation of frame-shaped samples made of different types of steels. Moreover, results of validating tests on steel are also presented. Determination of stresses in construction elements made of steel is especially important, if the structure is already in use for some time and subjected to various types of mechanical stresses and environmental conditions. For such assessment magnetoelastic effect based method may be used. However, significant limitation of such methodology is caused by limited knowledge about the stress dependence of magnetic characteristics for construction steels.

2. Methodology of measurement

In the figure 1 experimental setup for measurements of magnetic and magnetoelastic characteristics is shown.

Hysteresis loops measurements are done on a test stand composed of hysteresisgraph and personal computer. Hysteresisgraph HB-PL30 is composed of: voltage current converter, fluxmeter. The software generates magnetizing voltage signals, and sends them to the voltage current converter. The current goes to the magnetizing winding. Sensing winding is connected to the fluxmeter, where the voltage induced in the sensing winding is converted on the flux density value. The principles of applying tensile stresses with the use of oil hydraulic press were described previously [6]. In order to investigate the basic magnetic properties of the given construction steel, three conditions have to be fulfilled. The first condition is the obtaining of the closed magnetic circuit in the sample. Then the influence of the demagnetizing field on the measurements is greatly reduced, and the influence of the sample shape is nearly eliminated. The second condition is constant stress along the whole magnetic patch in the investigated sample. Acquiring this condition allows for elimination of the stress influences cancelling, which may happen when there are positive stresses in one part of the sample, and negative in another. The third, equally important condition is making the distribution of the effective stresses parallel to the magnetic patch direction in the sample.

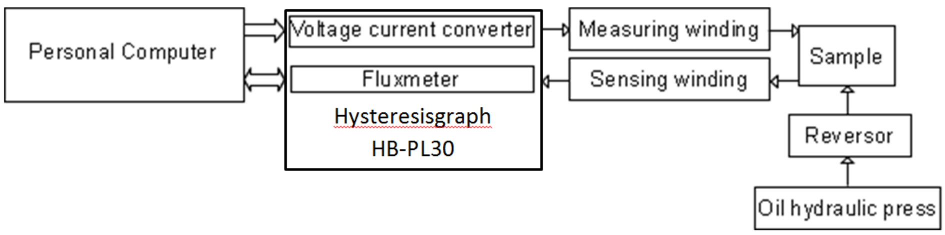

Fig.1: *Schematic block diagram of the computer controlled hysteresis graph system for magnetic and magnetoelastic testing.*

After careful considerations, the sample shape was designed, and is shown on figure 3. Developed sample fulfill all three of the previously mentioned conditions. The sample is composed of two sections. Section one is the measuring section, which two stress bearing columns, parallel to their surfaces. On the columns the magnetizing and sensing windings are located, so that the magnetizing field has closed magnetic patch and is parallel to the affective stresses direction. The second section is responsible for the mounting of the sample and transmission of stresses from the reversor.

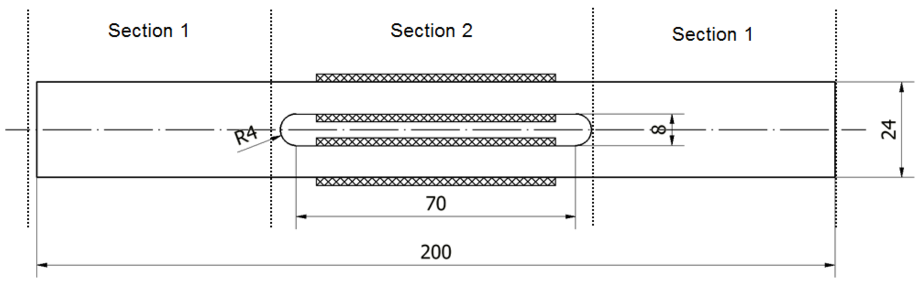

Fig.1: *Frame-shaped of construction steels which two section.*

3. Idea of stress state assessment

Due to the fact that for the forces acting on different cross sections there are different stresses in the samples, in this paper unified approach was used. Instead of forces acting on the samples, stresses are used for comparison of the samples with various dimensions. Another reason is the fact that the material is reacting directly on the stresses acting upon it, and indirectly on forces. Basic characteristics, which may be used for assessment of the influence of the stresses induced by the external forces are the B(H) hysteresis loops for various stresses values. On the base of these measurements, magnetoelastic $B(\sigma)H$ characteristics describing

the change of the maximal field density B as a function of the stresses for a given field strength H were determined.
Determination of these characteristics is exceptionally important because of the possibility of stress state evaluation. Exactly these characteristics, obtained from the precise measurements on the samples with closed magnetic circuit and homogenous stress distribution allow for the proper assessment of the stress state in the construction steel elements.

4. Results

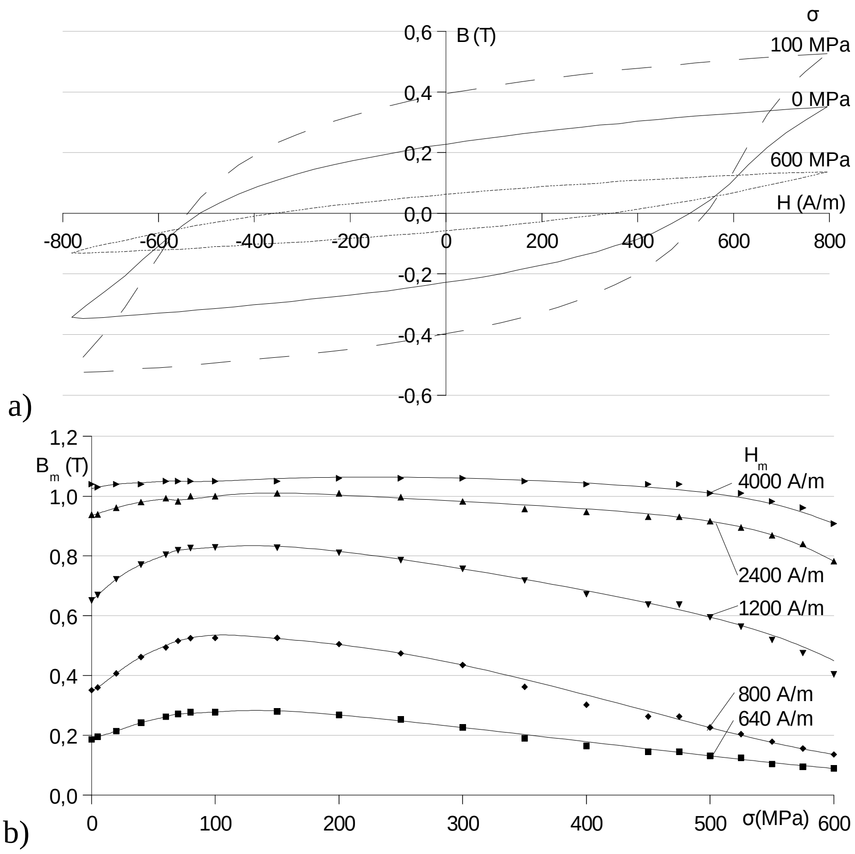

Fig.3: *a) The tensile stresses dependence of magnetic B(H) characteristics of frame-shaped samples made of X30Cr13 steel, for the amplitude of magnetizing field Hm= 800 A/m. b) The tensile stresses σ dependencies of flux density B in X30Cr13 steel.*

The subjects of the investigation were samples made of X30Cr13 construction steel. The measurement methodology was divided into two stages. In the first stage, unloaded wound sample was investigated for its magnetic properties. Next, after the analysis of these parameters, specific measuring points, dependent on the coercion field H_c, were designated. There were five determined points, 640 A/m , 800 A/m , 1200 A/m , 2400 A/m and 4000 A/m. In the second stage, the sample was mounted in the reversor, and was investigated for magnetoelasticity, i.e. magnetic properties as a function of applied stresses [8]. The range of the applied stresses was from 0 MPa to the destruction of the samples, at about 625 MPa. To obtain the same initial conditions, the sample was demagnetized before each of the measurements. Measurements were done for a set value of the tensile stress, in each of the above-mentioned magnetizing field points. Next, the applied stress value was changed, and another measurement series was done. Tensile stresses were changed in the increasing way. Figure 3a shows the influence of tensile stresses σ on the shape of B(H) hysteresis loops of frame-shaped sample made of X30Cr13 construction steel. Shape of the magnetic hysteresis loop changes significantly for the tensile stresses σ of up to 600 MPa. For magnetizing field with H_m = 800 A/m amplitude, the flux density B under such stresses decreases by 61%. Nonetheless, for lower amplitudes of magnetizing field H_m, the flux density B decrease under stresses is even more distinct. Figure 3b presents the magnetoelastic $B(\sigma)H_m$ characteristics. On these characteristics the maximum field density B may be observed. This maximum, called the Villari reversal point, is connected with minimal value of total free energy in the sample subjected to both mechanical stresses and magnetizing field. Under the tensile stresses value of flux density B in the sample first increases, and after reaching the Villari point it starts to decrease. It should be noted, that this decrease is most significant for about 500 MPa stresses, which is connected with the change from elastic to plastic deformation of the sample. These changes are more pronounced for lower values of amplitude of magnetizing field H_m. This occurs due to the fact, that in this case, participation of magnetoelastic energy in the total free energy is significantly higher. It should be stressed, that $B(\sigma)H_m$ characteristics may be treated as a standard of presentation of magnetoelastic properties of constructional steels. Such standard could be especially useful from the point of view of mechanical stress assessment during non-destructive testing of construction elements.

5. Conclusions

Method of magnetoelastic investigation presented in this paper creates new opportunity for description of magnetic characteristics stress dependences of constructional steels. Developed test stand allows for precise determination of these characteristics, which allow for the proper assessment of the stress state in the construction steel elements. Designed shape of the sample ensures closed magnetic circuit and obtainment of the uniform stresses distribution, parallel to the magnetic flux lines. Presented frame-shaped samples based methodology allows to bridge the gap in knowledge about magnetoelastic characteristics of different types of constructional steels. Results of experimental tests of X30Cr13 constructional steel validated proposed methodology of investigation. It was observed, that under the tensile stresses, for lower values of amplitude of magnetizing field H_m, the flux density B changes significantly. For this reason, presented experimental results confirm feasibility of use of magnetoelastic effect based measurements in industry-applicable non-destructive testing of constructional steels elements.

Acknowledgement

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