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Using the Automatic Calibration Machine MagStressACS to Establish Calibration Curves for S355 Steel

Z. Saternus*, T. Domański and M. Kubiak

Czestochowa University of Technology, Faculty of Mechanical Engineering, Dąbrowskiego 69, 42-201 Częstochowa, Poland

Doi: 10.12693/APhysPolA.145.778 *e-mail: zbigniew.saternus@pcz.pl

The paper presents physical aspects related to the preparation of the device and the cross-sample calibration process. The innovative automatic calibration machine MagStressACS was used to carry out the process. This device is an effective solution for quickly generating calibration curves of the dependence of the Barkhausen effect on the strain state for the biaxial stress state. A cross-calibration sample made of S355 steel was used in the tests. During the calibration process, 50 measurement points were assumed. Based on the experimental tests, calibration curves and two-dimensional calibration maps were obtained. The results constitute a basis for reference results for further research on the stress state and deformation of real steel constructions.

topics: Barkhausen effect, calibration process, calibration curves, S355 steel

1. Introduction

The determination of the stress state in industrial products is one of the key issues faced by measurement techniques [1–3]. Despite advanced manufacturing techniques, modern industry still encounters difficulties with the methodology for measuring the stress state in machine and structure elements. Measurement of stress is very difficult due to the complex state occurring in the material [1]. The most commonly used measurement methods are electro-resistance strain gauges and X-ray examinations [4, 5]. These methods focus on a point measurement of stress. Conducting the measurement process is quite difficult and laborious. It is necessary to select the most loaded points in the tested material and then appropriately prepare the surface of the tested elements.

Therefore, new methods with a simpler measurement are being developed, which would allow measuring the stress state at any location in the surface of construction without the need to prepare tested surface [1, 6, 7]. One of such solutions is the MagStress5D measuring system manufactured by NNT (Novel Nondestructive Testing) [8]. The specificity of this measuring device is based on the determination of the angular stress distribution in the material using a bidirectional Barkhausen effect probe [7, 9, 10]. The proposed measurement method allows for a quick measurement of the stress state in ferromagnetic materials [8, 11]. The non-destructive measurement method makes it effective in industrial environments [12]. The automated device is equipped with a magnetizing probe, which allows for a measurement lasting a few seconds. The result is information about the elastic deformation of the material in the direction parallel to the direction of magnetization. An important element of conducting research is the proper preparation of the measuring device.

In the presented research work, the main attention is focused on the calibration process of the device using a sample made of S355 structural steel. The intensity of the Barkhausen effect depends on various physical properties of the tested materials. The calibration procedure is necessary to determine the dependence of the Barkhausen effect intensity on the level of elastic strain [7]. According to the device manufacturer's recommendations, the most suitable calibration samples should be homogeneous. From a practical point of view, this is difficult to achieve, therefore the calibration procedure should be performed for a wide range of physical parameters. The automatic calibration process allows for a significant reduction of the time of preparatory work.

Based on the calibration measurements, two-dimensional distributions of the magnetic field intensity as a function of strain were obtained. In

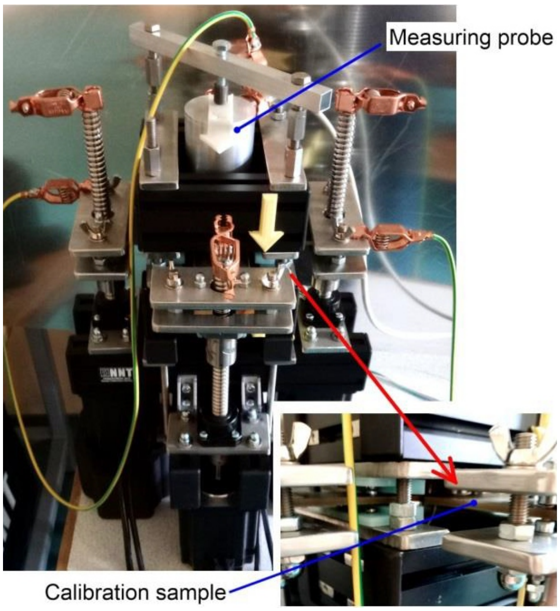

Fig. 1. Automatic calibration system MagStressACS.

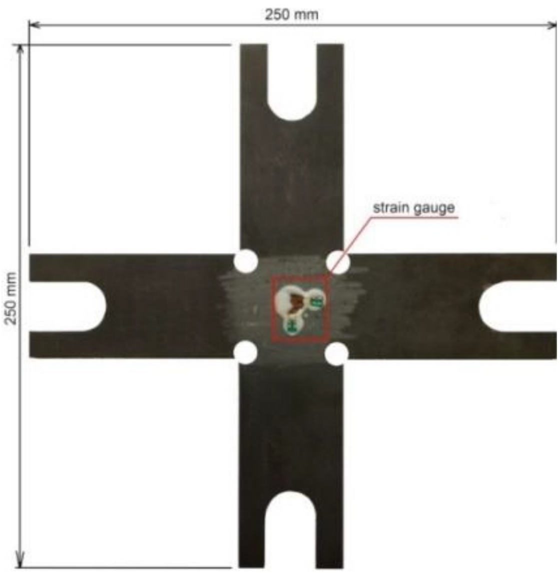

Fig. 2. Calibration sample — S355 steel.

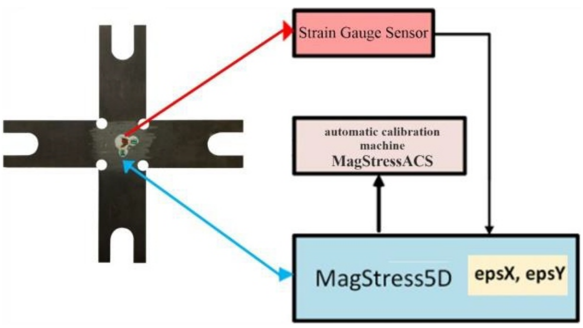

Fig. 3. Measuring system operation scheme.

the next stage of the measurement tests, the determined stress values are correlated with the calibration curves.

2. Measuring system

The automatic calibration process of the MagStress5D system is carried out on the MagStressACS automatic calibration device. It is an effective device enabling quick generation of calibration curves of the dependence of the Barkhausen effect intensity on the strain state for a biaxial stress state. Figure 1 shows the calibration device.

The device uses samples in the form of a cross (Fig. 2), on which a strain gauge sensor is placed (the device allows the use of bidirectional sensors or strain gauge rosettes).

As part of the calibration tests, three samples of 6 mm thick S355 carbon steel were made. The samples were cut with the waterjet machine from one sheet of metal. Chemical composition of S355 steel was: 0.19 C, 1.05 Mn, 0.2 Si, 0.08 Cr, 0.11 Ni, 0.006 Al, 0.028 P, 0.02 S [%] [13].

The operational scheme of the calibration device is shown in Fig. 3. During the test, the device cooperates with the Barkhausen effect intensity measuring head. The calibration process involves imposing a biaxial stress state by bending the sample in the shape of a cross. The four-point support of the two arms of the cross allows for the free generation of deformations in its central part. The level of deformation is recorded using a strain gauge sensor.

For the test samples, calibration was performed in the deformation range $\varepsilon = (-600\text{–}600) \times 10^{-6}$ in steps of 200×10^{-6}. The same magnetization parameters were used for all samples. For the assumed deformation parameters, 49 measurement points are obtained, as shown in Fig. 4.

Based on the measured angular distributions of the Barkhausen effect intensity, the signal intensity–strain relationships are determined.

3. Results and discussion

For the analyzed samples, Fig. 5 shows an example of the dependence of the Barkhausen effect intensity as a function of strain. The obtained results are two-dimensional maps for two perpendicular directions.

The obtained two-dimensional distributions provide full information about the influence of strains on the intensity of the Barkhausen effect. In the case of using the obtained calibration results in stress measurements, it is more convenient to use one-dimensional curves (Fig. 6).

The obtained curves will be used for further stress measurements using the MagStress5D measuring system.

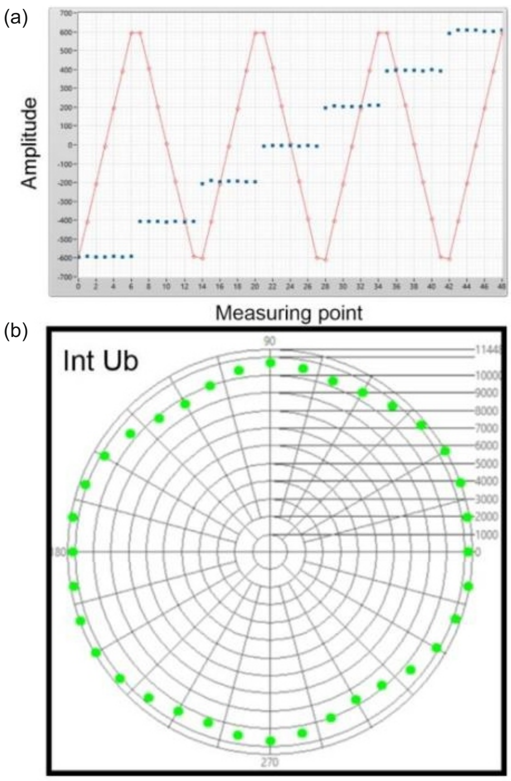

Fig. 4. Automatic calibration process: (a) measurement points, (b) Barkhausen effect intensity distribution in the angular sample.

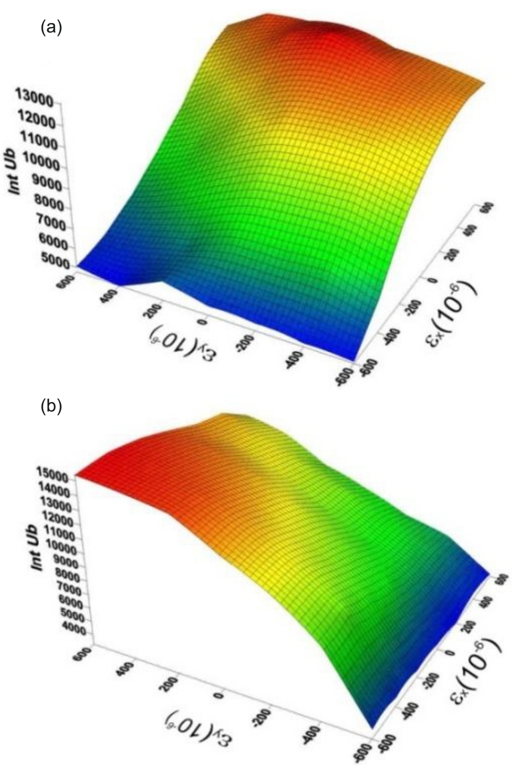

Fig. 5. Two-dimensional state of the Barkhausen effect signal intensity values: (a) along the measuring probe axis, (b) transversely to the measuring probe axis.

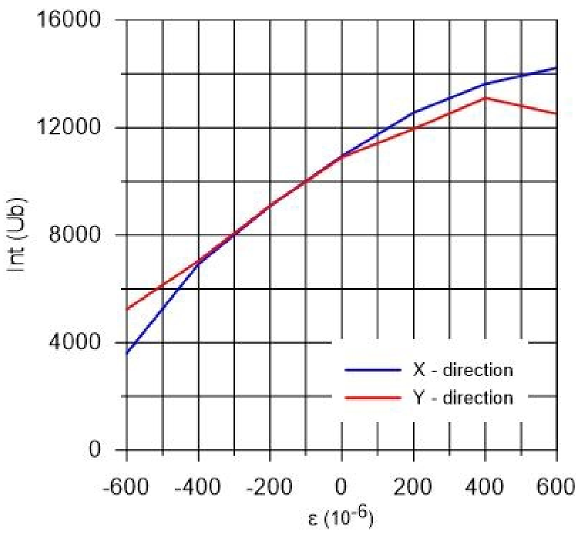

Fig. 6. Calibration curves of the Barkhausen effect intensity as a function of strain.

4. Conclusions

The MagStressACS automatic calibration device allows for quick and almost maintenance-free calibration of the MagStress5D measuring system. The most time-consuming step in the entire calibration process is the proper preparation of samples (making a calibration cross and mounting the strain gauge sensor). Performing a large number of measurements for different samples at different load ranges significantly improves the accuracy of the obtained results. The scaling results presented in this paper constitute the basis for further research on structural elements made of S355 steel. Alternatively, they can be used to measure elements made of steel with chemical and strength parameters similar to the tested material.

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