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UTILIZING MAGNETOELASTIC EFFECT TO MONITOR THE STRESS IN THE STEEL TRUSS STRUCTURES

Dorota Jackiewicz* — Roman Szewczyk — Adam Bieńkowski****

This paper presents possibility of magnetoelastic effect applying to monitor the stress in the streel truss structures. The investigation was performed on the truss made of 13CrMo4-5 steel. The three central truss members were wound with the magnetizing and sensing windings, and they form a triangular, closed magnetic circuit. Thus, the magnetic circuit is formed and closed by the truss construction itself, and there is no need to design or include in the construction any additional sensing elements. For the measurement of the magnetoelastic properties, special measurement stand was developed. It consists of the mechanical part for applying force to the steel truss, and thus stresses in the samples. The second part is the magnetic characteristics measurement system. During the magnetoelastic measurements, three member samples were installed into the truss. The truss was put under the mechanical load. The experimental results of measurements of the magnetic characteristics stress dependence of the sample magnetic circuit are very interesting. The stress dependence of the shape of magnetic hysteresis $B(H)$ loops can be observed for different amplitude values of magnetizing field H_m. Under the influence of external force, value of the flux density B decrease. The magnetoelastic $B_m(F)H_m$ characteristics for the sample magnetic circuit can be fit with the second degree polynomial. In presented case high agreement between the measurement results and curve fit was achieved, as shown by the coefficient of determination R^2 equal to 0,998. Knowing this characteristic, it is possible to calculate the force acting upon the truss on the basis of the magnetic induction measurement. When the force is known, one can calculate the tensile and compressive stresses in the magnetic circuit elements, namely the steel truss members. With the knowledge of the mechanical properties of steel we are able to determine whether the internal stresses in the truss are a threat to the structure.

Keywords: magnetoelastic effect, steel truss constructions, non-destructive stress evaluation

1 INTRODUCTION

Currently, steel structures require continuous monitoring of the external forces acting upon them, and internal stresses. This is particularly important in the case of bridges, halls, masts and electricity pylons, designed as truss constructions. In this case, there are components whose failure poses a threat to the entire structure, therefore it is especially important to monitor their stress state. Existing methods for assessment of such stresses, such as the strain gauge or magnetostrictive method [1, 2], have their major limitations. Thus there is a need to develop new methods for assessing the state of stress in structural elements. Recent trends indicate the rapid development of research in the field of magnetic testing, both for classic materials [3, 4], as well as new methods are developed [5, 6]. The magnetoelastic effect bases on the change of the magnetic properties of the material under internal stress from external forces. Currently, it is used in the construction of magnetoelastic force sensors [7, 8, 9]. Because of the non-destructive nature of the measurement, and the continuous operation potential, this effect is interesting to study for its use for on-line monitoring of load state in the given structure.

The Villari effect was successfully utilized for pipelines monitoring previously [1]. However, the possibility to utilize the magnetoelastic Villari effect for stress assessment and construction state monitoring in large steel structures (such as trusses) was not previously investigated.

In this paper the specially developed magnetoelastic method investigation of steel truss construction is presented. It allows for mechanical load assessment in the preselected members of the truss under external force influence. Steel trusses are widely used in medium and big scale constructions, such as electric grid power line distribution towers, bridges, pylons, halls etc., but without proper maintenance they are prone to catastrophic failures. It is especially important for energetic and civil engineering structures.

2 EXPERIMENTAL

To investigate the basic magnetic properties three requirements have to be fulfilled. Firstly, the closed magnetic circuit in the sample is essential. The demagnetizing field influence on the measurements is then greatly reduced, and the sample shape influence is nearly eliminated. Secondly, there should be uniform stress distribution along the magnetic circuit length of the sample. Acquiring this condition allows for elimination of the stress influences cancelling each other, which occurs when there are positive stresses in one part of the sample, and negative in another. The third, equally important condition is ensuring the distribution of the effective stresses parallel or perpendicular to the magnetic patch direction in the sample.

For the magnetoelastic tests, special member sample was developed. It is made of the 13CrMo4-5 constructional steel, widely used in the energetic industry.

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* Industrial Research Institute for Automation and Measurements PIAP, al. Jerozolimskie 202, 02-486 Warsaw, Poland, ** Institute of Metrology and Biomedical Engineering, Warsaw University of Technology, ul. Boboli 8, 02-525 Warsaw, Poland; d.jackiewicz@mchtr.pw.edu.pl

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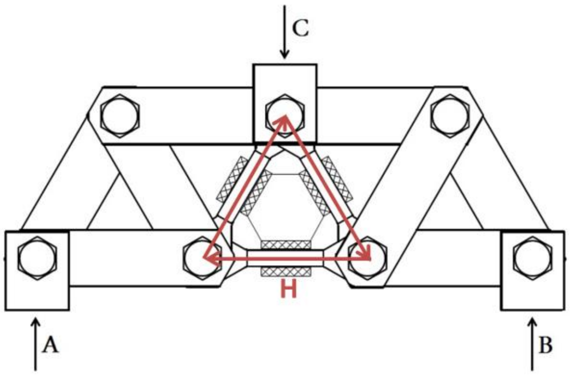

Fig. 1. Schematic of the experimental steel truss structure with marked magnetic circuit. A,B – support points; C – loading point, H - magnetic field

In the Fig. 1 the truss designed for magnetoelastic testing under varying mechanical load is shown. Three central members (figure 2) of the truss, that is the central bottom chord and the central webs, were designed as the test samples constituting the test magnetic circuit. Their cross-sections are significantly lower than in the other elements, in order to carry out destructive tests without any plastic damage nor significant elastic deformation of the rest of the structure. This ensures that the main part of the measurement stand is reusable.

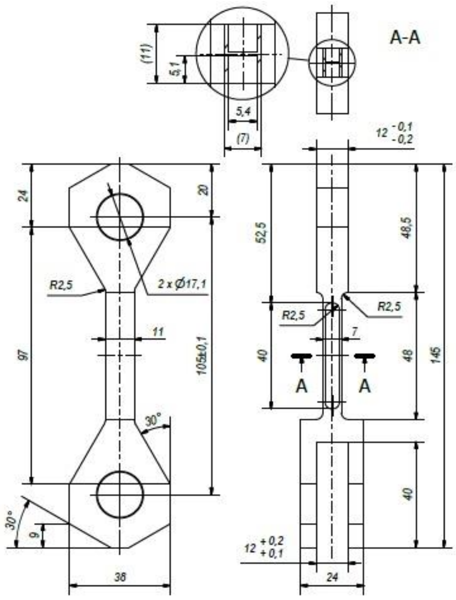

Fig. 2. Schematic diagram of the sample members

These three central truss members were wound with the magnetizing and sensing windings, and they form a triangular, closed magnetic circuit. Thus, the magnetic circuit is formed and closed by the truss construction itself, and there is no need to design or include in the construction any additional sensing elements.

Additionally, to reduce demagnetization effects, sensing winding was located under the magnetizing winding. In the presented investigation, each sample was wound by 300 turns of magnetizing winding (900 turns in the whole magnetic circuit), and 200 turns of sensing winding (600 turns in the whole magnetic circuit).

For the measurement of the magnetoelastic properties, special measurement stand was developed (Fig. 3). It consists of two parts. The first is the mechanical part for applying force to the steel truss, and thus stresses in the samples. The second part is the magnetic characteristics measurement system.

The hysteresis loops measurements are done on the hysteresisgraph, which is the specially developed test stand for magnetic hysteresis loop measurements.

The hysteresisgraph consist of three main parts:

- Source of magnetizing and demagnetizing signals
- Magnetizing electronic circuit connected to the sample's magnetizing winding, consisting of the precise voltage/current converter,
- Fluxmeter connected to the sample's sensing winding, measuring the magnetic induction in the sample.

System integration and control is provided via the PC.

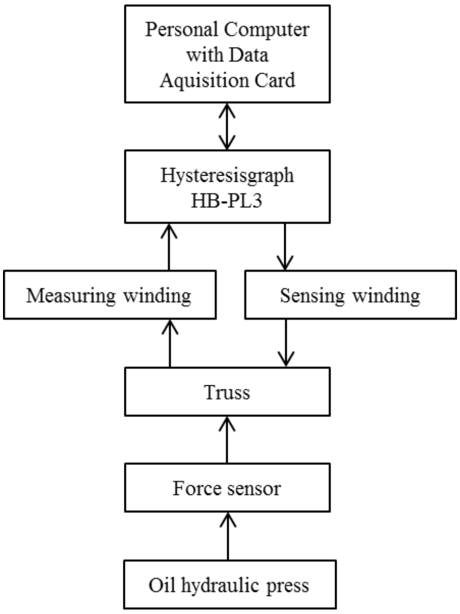

Fig. 3. Schematic block diagram of the special measurement stand

The mechanical part consist of the oil hydraulic press applying force to the steel truss and precise reference force sensor inside (Fig. 4).

The truss was supported on the bottom edge nodes (Fig. 1, A,B). The mechanical load was exerted vertically on the upper central node of the truss (Fig 1, C) by the oil hydraulic press.

During the magnetoelastic measurements, three member samples were installed into the truss. The truss was put under the mechanical load. The sample K01 (bottom chord) was stretched with tensile stresses, while the samples K02, K03 (webs) were loaded with compressive stresses (Fig. 1). The frequency of the magnetizing signal during the measurements was set to 0.1 Hz. The influence of the stresses on the shapes of the $B(H)$ hysteresis loops was measured for amplitudes of magnetizing field H_m equal to 350 A/m, 435 A/m, 655 A/m, 870 A/m, 1310 A/m and 2180 A/m.

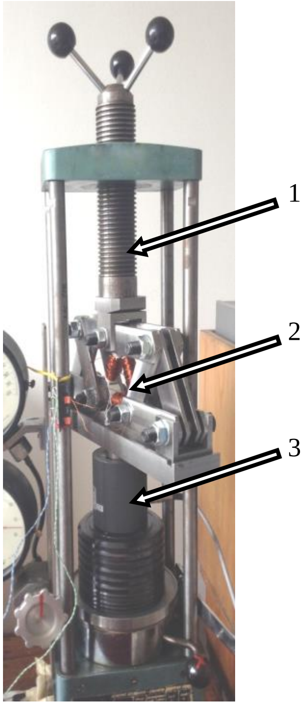

Fig. 4. Mechanical part of the system: 1 – Force exer-ting oil hydraulic press, 2 – steel truss, 3 – force sensor

The stresses in the member samples were calculated from the load, truss geometry and sample members dimensions (Table 1). The load was incremented, and hysteresis loop measurements were performed for the calculated stresses.

4 RESULTS

The experimental results of measurements of the magnetic characteristics stress dependence of the sample magnetic circuit are presented in Figure 5 for amplitudes of magnetizing field H_m equal to 350 A/m, and in Figure 6 for amplitudes of magnetizing field H_m equal to 655 A/m. The stress dependence of the shape of magnetic hysteresis $B(H)$ loops can be observed for different amplitude values of magnetizing field H_m. Changes of the basic magnetic parameters: flux density, remanence and coercivity are evident. From the technical application point of view, changes of flux density are most interesting. Figure 7 and 8 presents the magnetoelastic $B_m(F)H_m$ characteristics for the sample magnetic circuit. Under the influence external force, value of the flux density B decrease. Moreover, these changes are relatively higher for lower values of the amplitude of magnetizing field H_m. This is due to the fact, that for lower values of magnetizing field H_m, participation of magnetoelastic energy in the total free energy in the sample's material is significantly higher.

Table 1. Mechanical load applied to the truss. F – force exerted by the oil hydraulic press; σ – calculated mechanical stresses in the sample members

No.	F (kN)	σ (MPa)	
	force	tensile stress	compressive stress
0	0	0	0
1	0.51	20	13
2	1.02	40	27
3	1.52	60	40
4	2.03	80	53
5	2.54	100	67
6	3.05	120	80
7	3.56	140	93
8	4.06	160	107
9	4.57	180	120
10	5.08	200	133
11	6.35	250	167
12	7.62	300	200
13	8.89	350	233
14	10.16	400	267
15	11.43	450	300
16	12.70	500	333

The obtained characteristics can be fit with the second degree polynomial. In both presented cases high agreement between the measurement results and curve determination R^2 equal to 0,998. Knowing this characteristic, it is possible to calculate the force acting upon the truss on the basis of the magnetic induction measurement. When the force is known, one can calculate the tensile and compressive stresses in the magnetic circuit elements, namely the steel truss members. With the knowledge of the mechanical properties of steel we are able to determine whether the internal stresses in the truss are a threat to the structure.

5 CONCLUSIONS

Test stand for the investigation was designed and built, along which the special truss with interchangeable members, which allowed for installation of special sample members. It should be stressed, that there was no need to fabricate special openings in the sample members, or two-column cross-section geometries in order to wind the measuring and magnetizing windings. The sample magnetic circuit was simply composed of the three sample members. Magnetoelastic effect based method of mechanical load assessment in constructional steel truss structure was presented. Measurements of the hysteresis loops of the sample circuit were performed under varying mechanical loads, which allowed to obtain magnetoelastic $B_m(F)H_m$ characteristics.

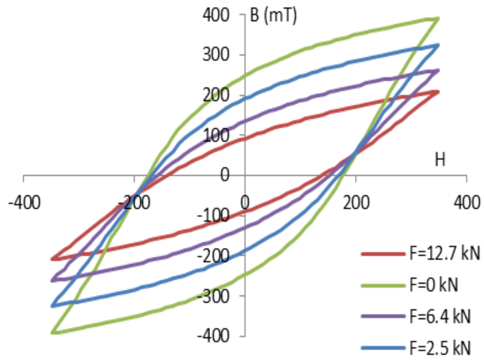

Fig. 5. Magnetic hysteresis loops of the sample magnetic circuit, under various mechanical loads. *H* - magnetizing field; *B* - flux density, *F* – force, H_m = 350 A/m

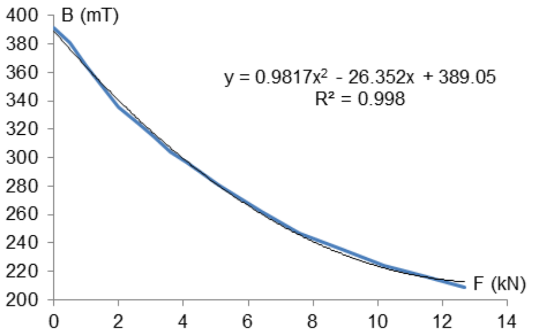

Fig. 7. Magnetoelastic $B_\mathrm{m}(F)H_\mathrm{m}$ characteristics for the sample magnetic circuit, H_m = 350 A/m

The constructional steel magnetoelastic characteristics are hardly influenced by the temperature [10], which is especially important for measurements under outdoor conditions. These characteristics can be accurately fitted with the second degree polynomial, which is very convenient from the application point of view. The results presented in the paper confirm the possibility of the magnetoelastic effect based measurements for NDT mechanical load assessment in the steel truss structures. The development of new non-destructive evaluation method for industrial applications is feasible. The measurements can be performed continuously for on-line monitoring of the given structure state. Moreover, the method is relatively low-cost, and neutral to environment and operators.

Acknowledgment

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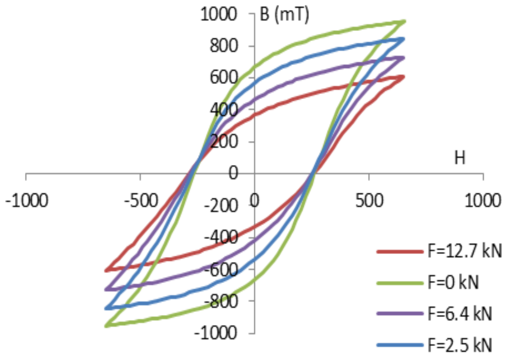

Fig. 6. Magnetic hysteresis loops of the sample magnetic circuit, under various mechanical loads. *H* - magnetizing field; *B* - flux density, *F* – force, H_m = 655 A/m

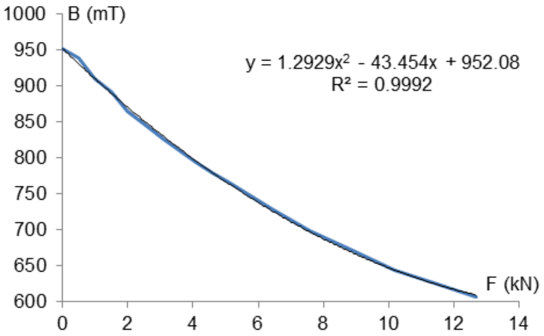

Fig. 8. Magnetoelastic $B_\mathrm{m}(F)H_\mathrm{m}$ characteristics for the sample magnetic circuit, H_m = 655 A/m

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