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MAGNETIC MEMORY INSPECTION OF AN OVERHEAD CRANE GIRDER – EXPERIMENTAL VERIFICATION

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Abstract

The safety and efficiency of material handling systems involve periodical inspections and evaluation of transportation device technical conditions. That is particularly important in case of industrial cranes, since they are subjected to a large impact load and mechanical stresses acting on the crane's structure and equipment. The paper considers the possibility of a crane structure inspection using the metal magnetic memory (MMM) method. As an advanced non-destructive technique, this method can be employed for inspection of crane structure during operation, which leads to reduce the down time costs and increase the safety confidence in the monitoring process. The MMM technique is effective for early identification of the possible defect location and detecting the micro-damage in ferromagnetic structures through detecting the stress concentration areas. The basic principle of MMM method is the self-magnetic flux leakage signal that correlates with the degree of stress concentration. This method allows detecting early damage of ferromagnetic material through performing measurement in the earth magnetic field, without the use of a special magnetizing device. The paper presents the experimental results carried out on the double-girder overhead travelling crane with hoisting capacity 1000 kg. The influence of the load variation and duration time on the intensity of the self-magnetic flux leakage signal is analysed and discussed.

Keywords: *overhead crane, metal magnetic memory method, damage detection*

1. Introduction

Regular maintenance and inspection of cranes under the manufacturer’s instructions and regulations in force should be carried out to ensure that the crane is safety to use and operators and other employees are not exposed to health and safety risks. The special care should be put on technical supervision of a large industrial crane’s structure, which is subject to a large impact load and mechanical stresses. Visual inspection of crane's structural components and equipment is common practice. However, some defects cannot be identified or are missed during the visual inspection or can be identified too late to take preventive action. Also, traditional non-destructive techniques (NDT) (e.g. ultrasonic, Eddy current NDT) are not able to determine stress concentration in crane structures, which can lead to cracks, or they require the artificial magnetization of a tested component.

Since the beginning of the eighties have been observed fast development of the new NDT technology, the metal magnetic memory, called also as residual magnetic field (RMF), which relies on the measurement of self-magnetic flux leakage (SMFL) arising in ferromagnetic and paramagnetic materials as a result of stress concentration zones under the influence of operational or residual stresses. The MMM NDT consists in registration and analysis of the normal H_y and tangential H_x components of the magnetic field and local magnetic anomalies. Their abnormal changes are observed on local stress concentration zones where a significant deformation is present due to an unsuitable combination of component features, structural heterogeneity, and workloads. So far, this technique is used only as a preliminary qualitative method of non-destructive testing in order to determine the possible danger zones in the structural elements. As the result of industrial researches made on this subject, it was proved that natural magnetization corresponds to the product's structural and technological heredity [3].

Numerous researchers over the past years have studied the MMM NDT reporting effectiveness of this technique in different applications and giving the significant contribution to development of metal magnetic method [1-4, 9, 11-16]. The implementation of the MMM NDT for inspection of crane structure and equipment is also considered in recent publications. The MMM NDT was applied to identify stress concentration zones in gantry crane beams [5]. Identification of damages occurring in a steel rope using residual magnetic field method reported in [6] can be successfully employed in crane's hoisting equipment diagnostic to enhance safety, predict and localize damage, and plan maintenance. Possibility of a real-time monitoring of a crane's structure using the MMM NDT and results of experiments carried out on the laboratory stand are discussed in [7, 8, 10].

This paper contributes to the study of crane's structure monitoring using the MMM NDT. As the advanced non-destructive technique, which does not require the use of a special magnetizing device, this method can be reliable alternative to classic methods used for crane's inspection. The MMM NDT can be employed for inspection of crane structure during operation (continuous monitoring), that can lead to reduce downtimes and increase the safety confidence in the monitoring process. The paper presents and discusses the results of the measurement experiments carried out on the double-girder overhead travelling crane with hoisting capacity 1000 kg. The SMFL was measured for the crane's beam in the sequence of experiments carried out for four days. The local stress concentration zones were identified and localized. Further analysis of the measured data results in data-driven approximation models of the SMFL variation.

The rest of the paper consists of section two presenting experimental setup, section three discussing the measurement results, and section four providing conclusions.

2. Experimental setup and measurement equipment

The experiments were carried out on the double-girder overhead travelling crane with hoisting capacity 1000 kg, span of the girders L = 8 m and trolley wheelbase a = 1.0 m. Fig. 1 and 2 present the crane subjected to examination and crane's girder cross-section, respectively, while Fig. 3 depicts the multi-channel flux-gate system used for the magnetic memory based inspection of the crane's girder.

Fig. 1. The double-girder overhead traveling crane with hoisting capacity 1000 kg

The magnetometer TSC-4M-16 (Tester of Stress Concentration) with scanning device were used for measuring, recording and processing of diagnostic data about stressed-strained state of the crane's girder. The scanning device is equipped with the incremental encoder and four flux-gate transducers spaced at 4 [mm] intervals. The transducers (magnetometers) installed in the scanning device allows to measure 2D distribution of SMFL signal along the surface of inspected structure. The sensor is used to measure the size of the magnetic field *Hp* and its components *Hy*, *Hx* in units [A/m].

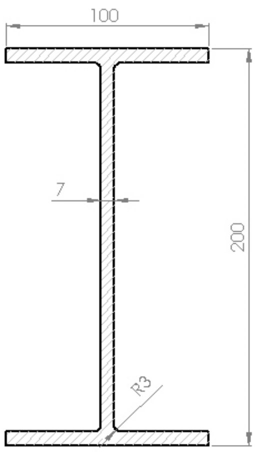

Fig. 2. Crane's girder cross-section

Fig. 3. TSC-4M-16 magnetometer with the scanning device

The 1.4 m length section of the crane's girder bottom surface, with the midpoint corresponding the middle of the crane's beam, was selected for examination using the MMM method. During the inspection, the crane's trolley was set in the middle of the crane's girder. Fig. 4 illustrates the major dimensional assumptions for the measurement experiments and location of the trolley during examination of the crane's girder. The four measurements were carried out daily for four days according to the following scenario repeated every day:

Experiment A – the experiment carried out when the crane is unloaded (m = 0 kg),

Experiment B – the experiment carried out immediately after applying the maximum load m = 1000 kg,

Experiment C – the experiment for the crane maximum load m = 1000 kg, carried out four hours after Experiment B (within 4 hours the crane girders are affected by m = 1000 kg),

Experiment D – the experiment carried out after four hours for the crane unloaded (m = 0 kg).

Hence, the selected section of the crane's girder was subjected to investigation using the MMM NDT during four days, each day measuring the magnetic field strength components in the sequence of four experiments: first measurement before loading the crane, two times after applying the maximum load m = 1000 kg with interval of 4 hours, and last measurement conducted immediately after unloading the crane (for m = 0 kg).

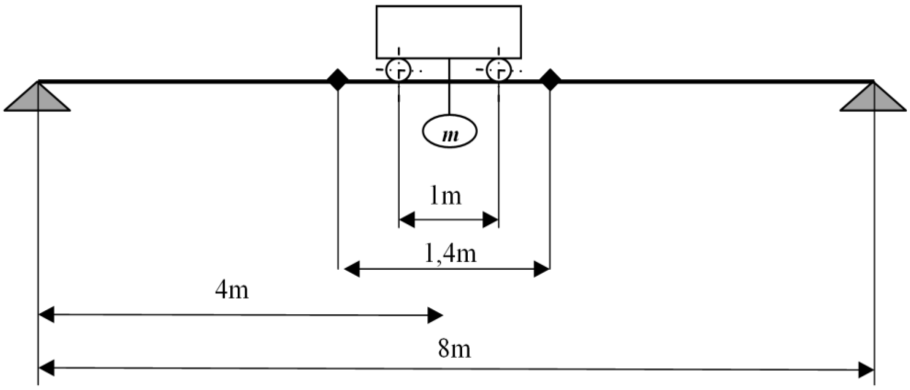

Fig. 4. Scheme and assumptions for measurement experiments

3. Results analysis

The results of Experiment A (before loading the crane) carried out during the first day is presented in Fig. 5, where the change of tangential and normal components of the magnetic field strength vector, H_x and H_y, respectively, and their gradients dH_x/dx and dH_y/dx are shown. The small anomaly of the magnetic field exists in the midpoint of the inspected section of the crane's girder, while within the interval 850-1150 mm there is observed significant change of magnetic field components gradients dH_x/dx and dH_y/dx.

Figure 6 presents the results of Experiment D carried out during the last day (4th day of experiments). The MMM NDT was applied for crane's beam inspection immediately after unloading the crane. There are evident changes in magnetograms comparing to the results from the first day (Fig. 5). There are observable changes of the magnetic field components H_x and H_y and their gradients dH_x/dx and dH_y/dx within intervals 0-650 and 1250-1400 mm.

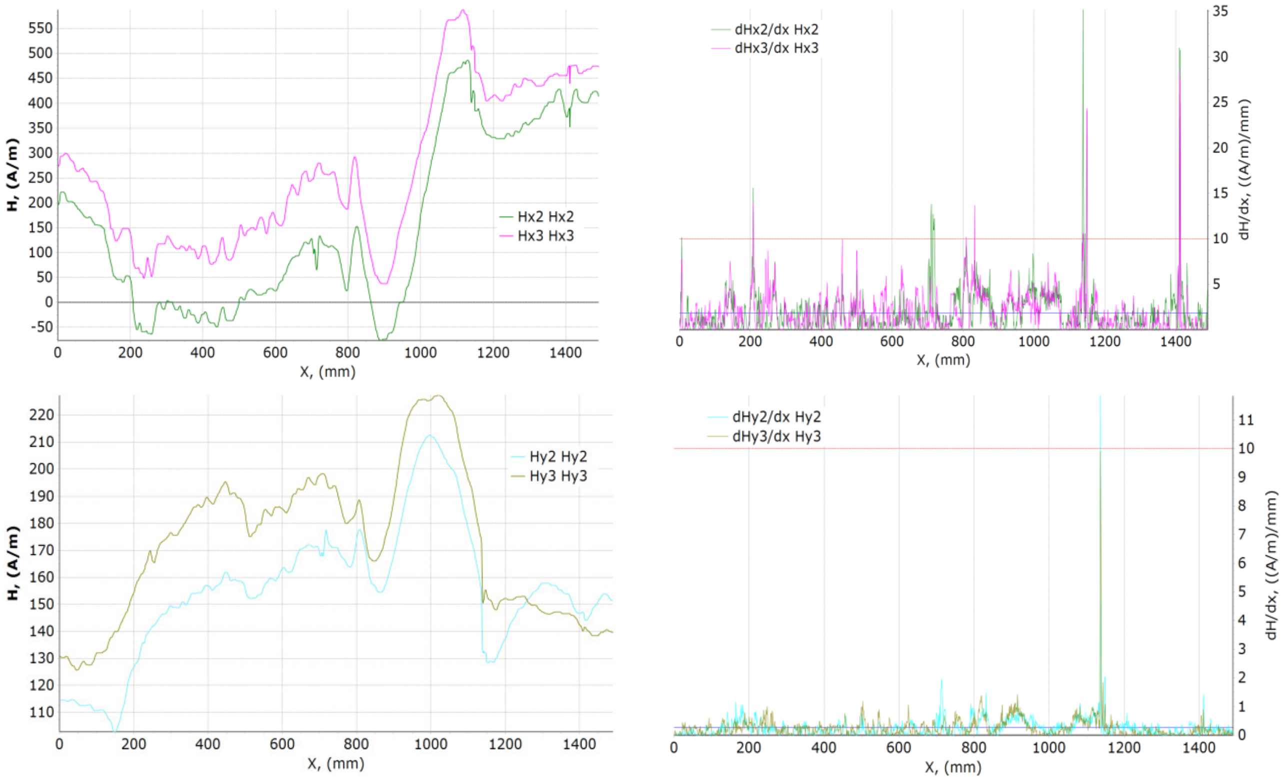

Fig. 5. Distribution of H_x and H_y, and their gradients dH_x/dx and dH_y/dx for Experiment A (1st day)

Fig. 6. Distribution of H_x and H_y, and their gradients dH_x/dx and dH_y/dx for Experiment D (4th day)

Tables 1 and 2 present the minimum, maximum and average values of magnetic field tangential component (H_x), maximum and mean value of magnetic field gradients (K), and the maximum value of M, which characterizes the ultimate strain capability of the material, measured in Experiment A (1st day) and Experiment D (4th day), respectively. The results confirm the load has influence on the magnetic field change in the crane's girder. However, there is ambiguity whether the magnetic field increase or decrease.

Tab. 1. Minimum, maximum and average values of tangential component and its gradient for Experiment A (1st day)

Channel	Hmin	Hmax	Havg	Kavg	Kmax	Mmax
Hx2	-76.3	486.3	154.8	1.868	35.197	18.842
Hy2	102.9	212.5	155.1	0.267	11.843	44.310
Hx3	37.8	587.6	263.6	1.838	28.516	15.513
Hy3	125.6	227.4	172.4	0.268	9.987	36.912

Tab. 2. Minimum, maximum and average values of tangential component and its gradient for Experiment D (4th day)

Channel	Hmin	Hmax	Havg	Kavg	Kmax	Mmax
Hx2	-72.5	508.8	190.8	1.390	27.801	19.995
Hy2	109.0	210.0	145.6	0.179	1.457	8.124
Hx3	52.1	614.3	303.8	1.449	38.884	26.843
Hy3	117.9	228.6	165.5	0.218	1.773	8.133

For further analysis the two points of the girder's section located at x = 750 mm and x = 1150 mm were taken into consideration, as at these points there are greatest changes of magnetic field gradients (Fig. 5 and 6). Fig. 7 and 8 present the maximum value of magnetic field tangential component H_x recorded at these points and using the two channels of the magnetometer TSC-4M-16, denoted $x2$ and $x3$, during 16 consecutive measurements carried out during four days (sequence of Experiments A, B, C and D repeated each day). The analysis of the measured data shows regularity in change of the magnetic field tangential and normal components H_x and H_y, respectively, that can be modelled through a data-driven approach. Thus, the models of SMFL variation were derived through the trend approximation by the 5th order polynomials (1)-(4) determined individually for each measurement point (x = 750 mm and x = 1150 mm) and magnetometer's channel ($x2$ and $x3$). The models can be further developed and updated during monitoring of the crane's girder and provide useful information for a decision-making process of maintenance operations.

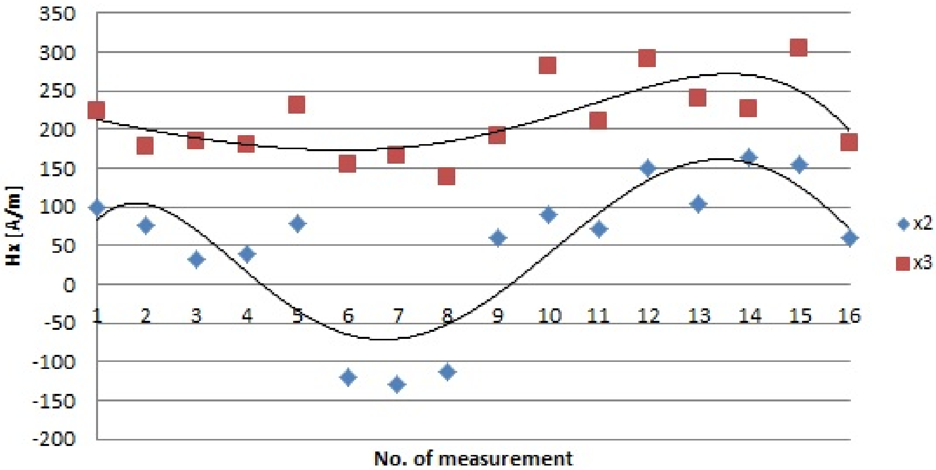

Fig. 7. Maximum values of H_x at measurement point x = 750 mm

The changes of the tangential component H_x (Fig. 7) measured using magnetometer channels $x2$ and $x3$ at the point x = 750 mm are approximated by the polynomials

$$Hx2_{750} = 0.0128x^5 - 0.6543x^4 + 11.557x^3 - 81.489x^2 + 193.55x - 40.606, \quad (1)$$

$$Hx3_{750} = -0.0023x^5 + 0.056x^4 - 0.4055x^3 + 2.4084x^2 - 18.36x + 229. \quad (2)$$

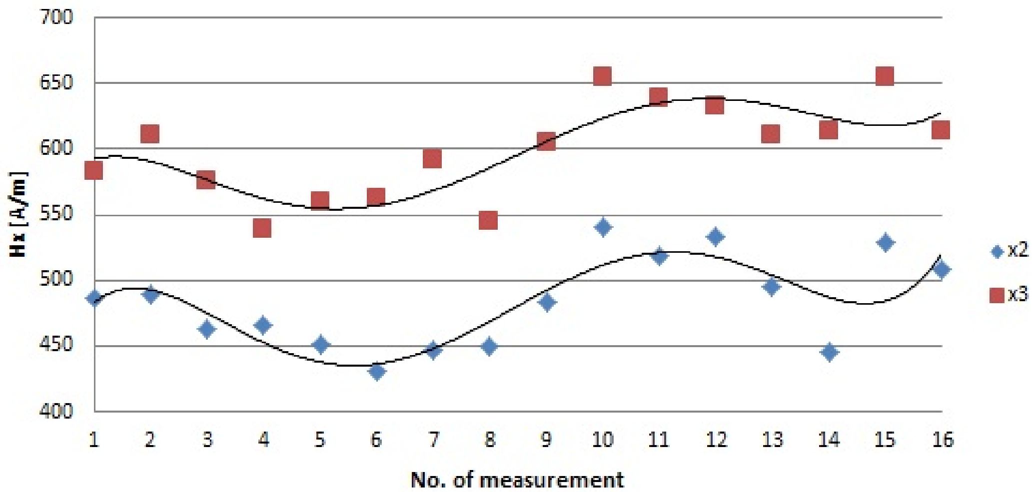

Fig. 8. Maximum values of H_x at measurement point x = 1150 mm

The changes of the tangential component H_x (Fig. 8) measured using magnetometer channels $x2$ and $x3$ at the point x = 1150 mm are approximated by

$$Hx2_{1150} = 0.0142x^5 - 0.5906x^4 + 8.6245x^3 - 51.669x^2 + 112.29x + 414.7, \quad (3)$$

$$Hx3_{1150} = 0.0079x^5 - 0.3314x^4 + 4.798x^3 - 27.226x^2 + 50.692x + 564.69. \quad (4)$$

4. Conclusions

The paper contributes to the study of crane's structure monitoring using the MMM NDT. As an advanced non-destructive technique, which does not require the use of a special magnetizing device, this method can be a reliable alternative to traditional methods used for crane inspections. The MMM NDT can be employed for inspection of crane structures and equipment during operation that can lead to reduce downtimes and increase the safety confidence in the monitoring process.

The paper discusses the results of measurement experiments carried out on the overhead travelling crane with hoisting capacity 1000 kg. The crane's girder was subject of inspections carried out for four days using the MMM NDT, while the crane was affected by the constant load mass for four hours per day. Crane girder daily inspections allowed identifying points of local stress concentration zones corresponding to the potential structural defects. Further analysis of the measured data shows consistency and regularity in change of the magnetic field tangential and normal components, H_x and H_y, respectively that can be modelled through a data-driven approach. The data-driven model can be updated by new data recorded during monitoring of the crane's structure focusing the special attention on stress concentration zones indicated by the SMFL anomalies. The models of SMFL variation can be useful in planning proactive actions and implemented in a decision-making process of maintenance operations. Thus, the results of experiments proved that the MMM technique can be successfully utilized in periodically made inspections, as well as continuous monitoring of a crane structure to improve effectiveness of material handling system proactive maintenance.

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