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CRANE FRAME INSPECTION USING METAL MAGNETIC MEMORY METHOD

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Abstract

The large industrial cranes carry out transportation operations in the presence of a large impact load and mechanical stresses acting on the crane's structure. The safety and efficiency of crane operations can be improved through providing the continuous structural health monitoring of crane's equipment and components. Advanced non-destructive techniques can be employed for inspection of cranes during operation, that leads to reduce the down time costs and increase the safety confidence in the monitoring process. Magnetic flux leakage methods of non-destructive inspection are widely utilized in identification of damaged areas in steel structures. However, the traditional magnetic flux leakage techniques are more appropriate in detecting cracks, but not sensitive to the detection of micro-defects. Metal magnetic memory is a relatively novel method of detecting the micro-damage in ferro-magnets due to the stress concentration. This method proved its effectiveness in early identification of the possible defect location. However, the method is preferable to off-line inspection due to the presence of operational variations in on-line measurements that can cause false indications of damage. In this paper, the problem of continuous inspection of crane's frame using the metal magnetic memory method is considered. The influence of operational variations on the self-magnetic flux leakage signal is investigated and quantitatively analysed based on the experimental results obtained on a laboratory-scaled overhead travelling crane.

Keywords: *overhead crane, continuous inspection, metal magnetic memory*

1. Introduction

Different types of cranes, such as container cranes, overhead cranes, tower cranes, jib cranes are extensively used for shifting goods in building sites, shipping yards, container terminals and many manufacturing segments. The large industrial cranes carry out transportation operations in the presence of a large impact load and mechanical stresses acting on the crane's frame and equipment. Visual inspection of crane's structural components and equipment is common practice. However, as the crane is exposed to a highly dynamic loading and it works in different environmental conditions, the different types of defects can occur, which could be not identified or missed during the visual inspection, or can be identified too late to take preventive action. The off-line periodic inspection can be carried out utilizing the non-destructive technology, such as ultrasonic method, X-ray or eddy current detecting techniques. However, the safety and efficiency of crane operations can be improved through ensuring the continuous structural health monitoring of crane's components. Advanced non-destructive techniques can be employed for monitoring the health of crane components during operation reducing the down time costs and increasing the safety confidence in the monitoring process.

Magnetic flux leakage (MFL) methods of non-destructive inspection are widely utilized in identification of damaged areas in steel structures [5]. However, the traditional MFL techniques are more appropriate in detecting cracks, but not sensitive to the detection of micro-defects. Metal magnetic memory (MMM) is a relatively novel method introduced by Anatoly A. Dubov [1-3], that proved its effectiveness in detecting the micro-damage in ferro-magnets due to the stress concentration [4, 8-10]. The basic principle of MMM method is the self-magnetic flux leakage (SMFL) signal that correlates with the degree of stress concentration [6-8]. 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 addresses the problem of continuous inspection of crane's frame using MMM method. The traditional non-destructive techniques are preferable to off-line inspection due to the presence of operational variations in on-line measurements that can cause false indications of damage. The on-line inspection requires removing the effect of operational loads. The load variation, position of motion mechanisms and the transient states of driving system can influence on the effectiveness of crane's components inspection. Thus, the influence of operational variations on the SMFL signal generated by the MMM sensor is experimentally verified and quantitatively analysed in this paper. The paper presents the experimental results carried out on a laboratory scaled overhead travelling crane. The MMM technique has been applied for the inspection of a crane's girder for the different operational conditions: varying load and trolley position.

The paper is organized as follows. Section two describes the experimental setup, measurement equipment and the applied method. The results of experiments carried out using the MMM method subject to the operational variations are presented and discussed in section three. Section four presents the final conclusions.

2. Experimental setup and measurement equipment

The experiments were carried out on the laboratory double-girder overhead travelling crane with hoisting capacity 150 kg, span of the girders L = 2.4 m, trolley wheelbase a = 0.3 m, and the trolley travelling range D = 2.2 m (constrained by the limit switches). The crane bridge and trolley are driven by the DC motors controlled using the FX2N Mitsubishi programmable logic controller (PLC). The push-button control panel or/and the PC with I/O board (PCI-1710HG control-measurement card) connected with the PLC can be used to control crane motion mechanisms: double-girder travelling bridge, trolley and hoisting. The position of the motion mechanisms is measured using the incremental encoders attached to the wheels of the bridge and trolley, and to the rope drum (used to measure the rope length). The strain gauge, which is supplied by the ADAM-3016 module, is used to measure the strain in the midpoint of a girder.

Figure 1 and 2 presents the laboratory stand and the multi-channel flux-gate system used for the magnetic memory based inspection of the crane's girder. The flux-gate 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 manufactured in form of a 4-wheel trolley with flux-gate transducers and a length-counting device. The transducers (magnetometers) installed in the scanning device allows to measure 2D distribution of SMFL signal along the surface of inspected structure. The results of experiments, which are presented in this paper, were obtained using three magnetometers installed in the scanning device.

The MMM method uses natural magnetization and after-effect displayed as the magnetic memory of metal to actual strains and structural changes in products and equipment metal. Measuring magnetic field distribution can show locations of the stress concentration zones (SCZs) and defects of material structure. The magnetization changes occurs in the zones of dislocations stable slip bands under the influence of operational or residual stresses or in the zones of maximum inhomogeneity of metal structure in new products [2]. The gradient of the H_P magnetic field tangential and normal component in SCZs is determined as follows [2]

$$K_{in} = \frac{|\Delta H_P|}{\Delta x}, \tag{1}$$

Fig. 1. The laboratory overhead travelling crane

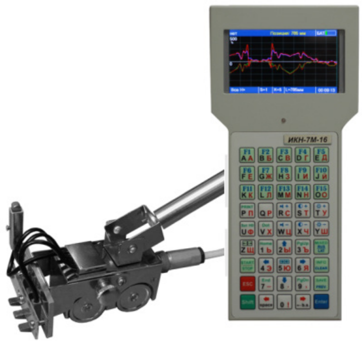

Fig. 2. TSC-4M-16 magnetometer with the scanning device

where: K_{in} is the magnetic leakage field gradient or the stress intensity magnetic factor, $|\Delta H_P|$ is the absolute value of the H_P field increment related to the increment of sensor position Δx. The gradient of SMLF correlates with the density of dislocations.

Distribution of the SMLF measured by special devices can highlight areas of potential crack initiations. According to many experiments reported in the literature, the specific characteristics of varying magnetic field intensity are observed at the possible defect location. This specific change of the SMLF signal consists in changing over the sign of the normal component of SMLF, while the tangential component of SMFL reaches a local extreme. These observations are illustrated in Fig. 3 presenting the results of experiment carried out on the laboratory scaled overhead crane. The MMM method was employed to off-line inspection of the crane's girder: the motion mechanisms were switched off and the girder was loaded only by the mass of the trolley located at the end of the girder. The three magnetometers were used to measure the tangential H_{Px} and normal H_{Py} components of the SMLF signal along the girder length L = 2.4 m. Fig. 3 presents the H_{Px} and H_{Py} and their gradients dH_{Px}/dx and dH_{Py}/dx. The inspection exhibited, that the potential defect is located between x = 0.93 m and x = 0.94 m from the girder origin (where x = 0 is the starting point of measurement). At this point, the H_{Px} riches the extreme value (above - 4000 A/m), and the H_{Py} changes its polarity. Further analysis of the results presented in Fig. 3 are provided in next section, and compared to the SMFL signal measured under the operational variations: varying load and transient states of the trolley and hoist driving systems. However, it should be also mentioned, that the MMM technique is efficient to identify location of a possible defect, but the influence of the defect characteristics on the magnetic field intensity is not clear.

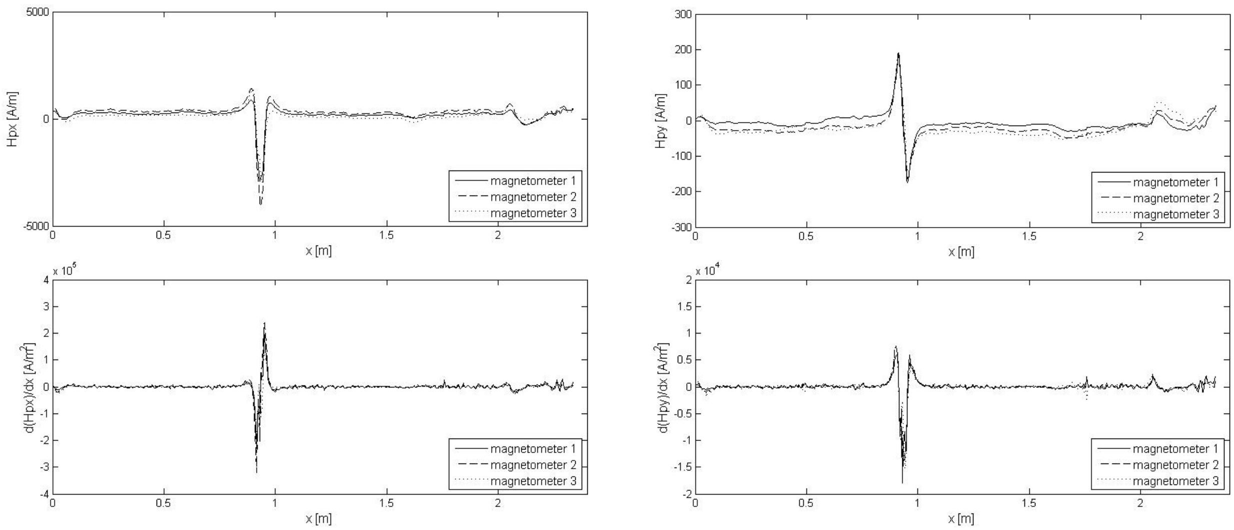

Fig. 3. Distribution of H_{Px} and H_{Py} and their gradients dH_{Px}/dx and dH_{Py}/dx along the surface of inspected crane's girder (x – axis direction)

3. Analysis of the experimental results

In this section, the quantitative analysis of the experimental results carried out for varying operational conditions is presented. The objective of the experiments was to measure the changes of the SMFL signal subject to the varying load and trolley position transferred a payload along the bridge's girders. The experiments were divided into two groups, denoted A and B. The assumptions for the experiment A are presented in Fig. 4.

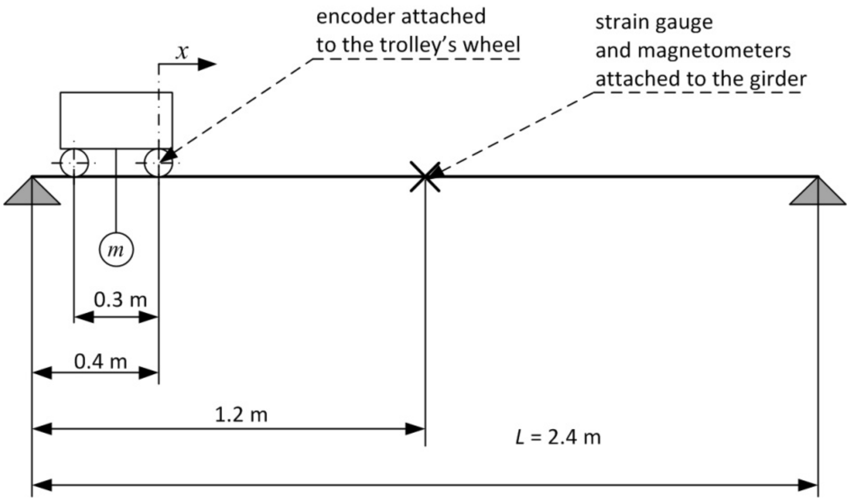

Fig. 4. Schematic view of the trolley transferring a payload of mass m along the crane's girder: assumptions for the experiment A

The magnetometers and strain gauge were attached in the middle point of the crane's girder (x = 0.5L = 1.2 m) to measure the magnetization and operational stresses, respectively. The incremental encoder (100 pulses per revolution) attached to the trolley wheel was used to measure the trolley position. The trolley initial position was x = 0.4 m distance from the origin of the crane's girder (taking into consideration the trolley wheelbase a = 0.3 m, and 0.1 m distance between the edge of the girder and the limit switch). Thus, the trolley location x on the girder is assumed as the position of the trolley wheel with the attached encoder. In the first experiment, the magnetization was measured during the trolley transfers the payload of 110 kg mass from starting point 0.4 m to the end of the girder (the limit switch located at about x = 2.3 m). Hence, the objective of the experiment A was to investigate the influence of the trolley position and stress variation on the SMFL signal measured in the middle point of the crane's girder. The results of the experiment A are presented in Fig. 5, in the form of operational stresses P, the H_{Px} and H_{Py} components of the SMFL signal, and their gradients dH_{Px}/dx and dH_{Py}/dx versus the position x of the trolley transferring the payload of 110 kg mass.

According to Fig. 5, the maximum value of stress (about 27 MPa) in the middle point of the girder is observed for the position of the trolley x = 1.425 m (x = 0.5L + 0.75a, where L is the length of the girder, a is the trolley wheelbase). The varying operational conditions (trolley position and stress) cause the changes of the SMFL signal measured in the middle point of the girder 0.5L. However, the variation of the both, tangential and normal components, has the different form than in case of the variation of the SMFL signal observed in Fig. 3, close to the SCZ identified between x = 0.93 m and x = 0.94 m. The change of trolley position from x = 0.4 m to x = 1.2 m (where x = = 1.2 m is the location of the magnetometers) causes the change of the tangential component H_{Px} from 172 to 119 A/m, from 255 to 161 A/m, and from 210 to 163 A/m for magnetometers 1, 2 and 3, respectively. Similarly, the normal component H_{Py} changes the value from –12 to –6.6 A/m, from –3 to 4.4 A/m, and from 5 to 16 A/m for magnetometers 1, 2 and 3, respectively. Thus, the maximum change of the SMFL signal is 94 and 11 A/m for H_{Px} and H_{Py}, respectively. The value of

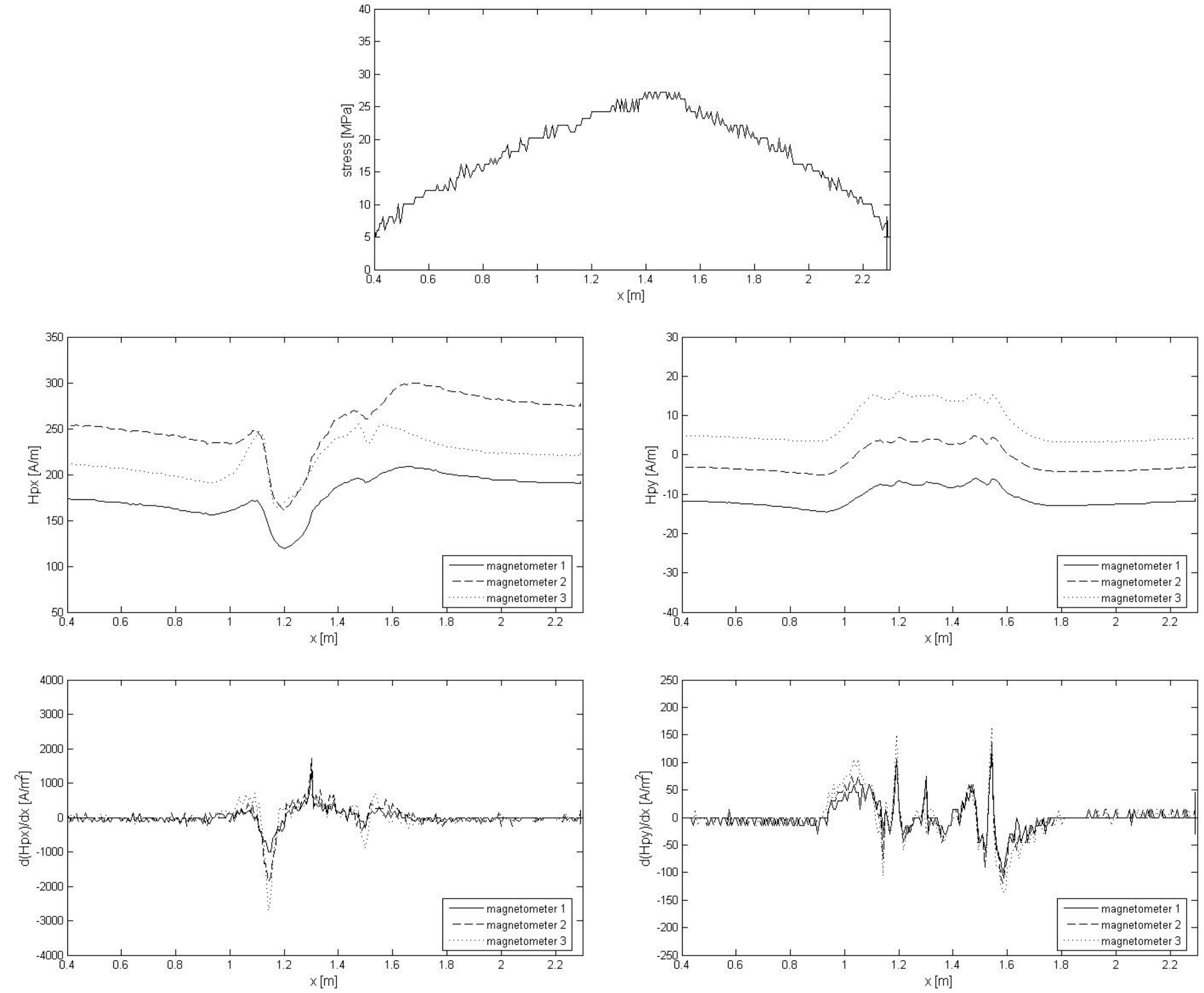

Fig. 5. Results of the experiment A: the stress, SMFL tangential HPx and normal HPy components, and their gradients dHPx/dx and dHPy/dx measured in the middle point of the girder

the normal component H_{Py} of the SMFL signal is close to its maximum value when the trolley is above the sensors (between x = 1.2 m and x = 1.5 m), and tends toward its initial value when the trolley position approaches to the end of the girder (x = 2.3 m). The maximum value of the tangential and normal components gradients dH_{Px}/dx and dH_{Py}/dx (regarding the position of the trolley x) are about -2700 and 165 A/m^2, respectively. Comparing to the results presented in Fig. 3, the possible defect location between x = 0.93 m and x = 0.94 m causes that H_{Px} maximum value is about –4100 A/m, the normal component H_{Py} changes its polarity between –200 and 200 A/m, while the gradients dH_{Px}/dx and dH_{Py}/dx riche the values 320000 and –18000 A/m^2, respectively. Thus, the results of experiments presented in Figs. 3 and 5 confirm that the SMFL signal has different form, either caused by the varying operational conditions (trolley location, operation strain and stress), or in case of SCZ identified at the possible defect location.

The next experiment (B) was carried out for the following conditions: i) the trolley was used to transport the payload of 110 kg mass to the point x = 1.2 m (the trolley's wheel was at the point of the girder at which the strain gauge and magnetometers were attached), ii) the trolley's motion mechanism was switched off. During the experiment, the payload (initially lifted up) was lifted down and again lifted up. Fig. 6 presents the strain measured using the strain gauge and the H_{Px} and H_{Py} components of the SMFL signal measured using the three magnetometers. It should be noted, that during the trolley motion from position x = 0.4 m to x = 1.2 m, the changes of H_{Px} and H_{Py} were similar as observed in Fig. 5. When the trolley was stopped at x = 1.2 m, and the payload was lifted down and up, the small change of the SMFL signal is identifiable (Fig. 6). In addition, some variation of the SMFL signal is observed during the transient states of the hoist. The initial value of the H_{Px} is –278.5, –187.5 and –22.5 A/m for magnetometers 1, 2 and 3, respectively. After lifting down the payload, the H_{Px} is –274.3, –184 and –18.4 A/m, and after lifting up it is –277, –185 and –21.5 A/m for magnetometers 1, 2 and 3, respectively. Similarly, the initial value of the H_{Py} is –14.1, 6.1 and 21.6 A/m, while after lifting down the payload its value is –13, 7.3 and 23 A/m, and after lifting up it is –14.3, 6 and 21.5 A/m for magnetometers 1, 2 and 3, respectively.

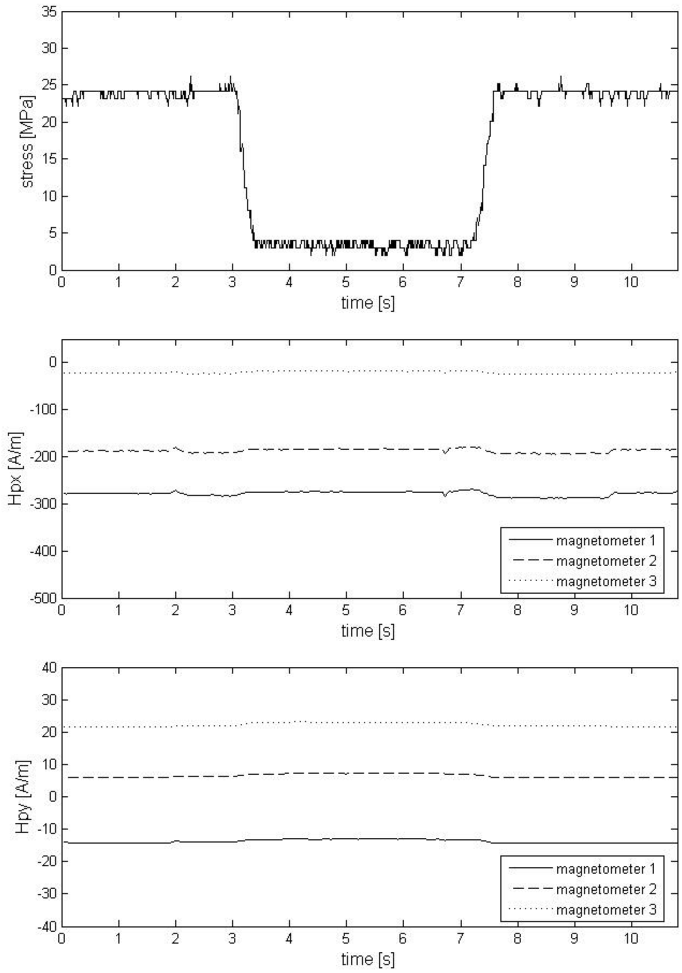

Fig. 6. Results of the experiment B: the stress, SMFL tangential HPx and normal HPy components measured in the middle point of the girder during the lifting operations

The analysis of the results obtained during experiments carried out on a laboratory stand confirms that the SMFL signal measured using the MMM technique depends on the operational variation such as dynamic loading, mechanism motions and transient states of the driving systems. However, the influence of working loads and transient states has a different form than in case of the SCZ identified at the possible defect location. Thus, the disturbances caused by the operational variation can be easily identified and removed from the diagnostic signal. However, further research activity should be addressed for this problem, and experimental verification should be carried out on a real material-handling device.

4. Conclusions

The possibility of the implementation of MMM method in continuous inspection of a crane structure is investigated in this paper. The safety and efficiency of crane operations can be enhanced by the continuous structural health monitoring of crane's components using the advanced non-destructive inspection methods. The MMM method proved its effectiveness in early identification of the possible defect location. However, the method is preferable to off-line inspection due to the presence of operational variations in on-line measurements that can cause false indications of damage. The on-line inspection requires removing the effect of operational loads and disturbances caused by the transient states of driving systems. This paper presents the results of experiments carried out on the laboratory scaled overhead travelling crane, in which the influence of varying load and trolley position on the SMFL signal components is considered. The experiments proved that the magnetic field intensity is sensitive to the operational variation such as dynamic loading, mechanism motions and transient states of the driving systems. However, the characteristics of these changes are different comparing to the characteristics of the SMFL signal observed at the possible defect location. Thus, the disturbances caused by the operational variation can be easily identified and removed from the diagnostic signal. However, the above conclusions should be verified experimentally on a real material-handling device.

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