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Research articles

Identification of magnetomechanical phenomena in a degradation process of loaded steel elements

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ABSTRACT

The search for new methods of determining the degree of stress of steel structures and the methods of detecting early phases of defect development are still proceeding. These allows to enhance the safety of use of machines and construction structures. The paper presents the description of a measuring apparatus, the method of measurements and the results of the research carried out at test beds with a focus of acquiring new sources of information regarding the technical condition of construction materials. In the long run, such information could prove useful for the diagnosis of objects made of various types of materials that have magnetic properties. Authors points out the basic problems encountered while searching for diagnostic information in magnetic signal, which comes from the complexity of stress effective magnetization. The proper model of magnetization was introduced which leads to original method which based on the special measurement and on dedicated processing of obtained signals. Relevant experiment was performed which concerned a two-dimensional measurement and analysis of own magnetic field of a construction steel sample for three various degrees of effort. The key point was to identify and separate reversible and irreversible magnetomechanical effects according to proposed method. The results proofs of existence of detail diagnostic information which is possible to discover. The results of the research lead to improvement of the existing measuring approach for passive magnetic methods and reduce the risk of omissions of diagnostically valuable diagnostic information. This paper ends with a summary of the obtained results while focusing in particular on the utility value of the approach for the purpose of diagnosis and its further development.

1. Introduction

In contemporary diagnostics, nondestructive testing plays an increasingly important role in the diagnosis of the state of technical objects. While referring to the current state of knowledge, it is worth stressing that in the case of steel structures, concrete structures and machines, attention is now mainly focused on detecting faults and defects at the earliest stage of their development. Thanks to continuous evolution, new techniques have emerged that are based on innovative ideas. Apart from the evolution of state-of-the-art techniques such as video-thermography, a group of methods based on magnetic phenomena exists that deserves particular attention. Magnetic techniques are considered, complete with supersonic, radiography, eddy currents and penetration testing methods as the top five effective NDT inspection categories. The most popular magnetic methods include the magnetic crack detection (as for example magnetic particle detection) and magnetic flux leakage detection (MFL). They provide for detection of surface or sub-surface faults in ferromagnetic metal parts of different shape and size and of smooth or rough surface finish. But the method of eddy current detection, however belonging to the same electromagnetic detection group, is not utilizing lines of force but makes use of the induction phenomena. Both methods of approach are useful for detection of the most dangerous faults: surface flat narrow gap cracks. Notwithstanding their very important role in technical diagnostics, they are limited to detection of the faults already existing. Additionally, bearing in mind the consequences of unpredictable construction disasters and technical object breakdowns, it becomes necessary to advance the science in the direction of a technology that is able to detect early phases of fault development. From the methods to be effective in detection of such defects in the just developing phases there could be mentioned magnetic methods which rely on the characteristic magnetic and magnetic domain behavior [5,7,18].

In parallel with the development of active diagnostic methods [8,19], we also see the development of a group of passive diagnostic

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methods [11,17,24,27], which all have the advantages of active methods but application of passive technique is in many aspects more advantageous than the commonly known and practically applied active magnetic methods. Passive methods do not require artificial magnetic sources, which makes it possible to use them not only for casual diagnosis, but also for permanent diagnostic monitoring and for the applications where such artificial magnetic sources should not be used for example, for the safety reasons. Unquestionable advantage of these methods is that no preparation procedure is required for the object under control, while actual measurements could be carried out in the not easily accessible places, under various conditions including remote checks. In addition, the testers are of small size, and can be auto powered and relatively inexpensive. But the top beauty of the device is that it is capable to detect the low energy fault generation phases.

From the point of view of the contemporary diagnostics the most interesting is the metal magnetic memory method (MMM), which is a passive technique. Research workers dealing with the magnetic memory method MMM declare its capacity in detection not only cracks, but also in location of the early phase of metal fatigue and structural defects, which might be represented by the stress concentration zones and by local anisotrophy of metal. In the magnetic memory method MMM use is made of the effects of cyclic and limit loads on the material structure which once have been stored and are subject in the procedure to observation with use of the natural magnetic leakage field NMFL. The actually applied model of the phenomena occurring within the tested object which affect the outcoming signal is oversimplified with the dominating residual magnetization considered as the common source of information in the process of identification of the cracks, subsurface blisters, inclusions or corrosion pits as well as of the changes in magnetic permeability related to stress concentration. In this stead the results of our work indicate the feasibility to deliberately extend physical description and records (for the approach of passive witness of the status) as well as interpretation of the magnetic field providing for effective approach to the new information on the stress-strain state of the material immediately before the fault occurred and on efficient operation of the engineering object.

Some problems must be solved to enable such wide application of passive magnetic methods. The diagnostic symptoms that exist in a magnetic field signal during a passive measurement have low levels as a rule, and hence the first issue to resolve is the determination of the relevant sensitivity of the sensor. The practice demonstrates that the level of the background magnetic field is often very high. Thus, an ideal sensor would be one with a wide measuring range and high sensitivity. In most cases, the two requirements cannot be fulfilled simultaneously. The next issue is the method of observation of the magnetic signal. It could be a point of measurement, a measurement on a certain observation plane, or a spatial (3D) measurement. In the last case, it could happen that the measurement that relies on the magnetic field sensor may prove insufficient. In such a case, it could prove useful to integrate it with inertial sensors to determine the angular orientation of the magnetometer or to integrate it with a view from a camera [23]. Merging the information from numerous additional sensors may prove key in the proposed broad diagnostic approach. From a technical point of view, there should be no limitations in terms of the possibility of carrying out each of the above listed measurements; however, the selection should depend on the specific nature of the diagnosed object and the degradation processes that it is subjected to. Even if a measurement system is built that will cope with any measurement strategy, there will still be the problem of visualization of the measurement results, especially when a spatial distribution of the magnetic field around the object is considered. It is a key issue, since it is the main factor that will decide whether we are able to interpret the results. The last stage, which is key from the point of view of diagnosis, is to find the diagnostic magnetic parameter that will be sensitive to the degradation-caused changes that develop in the examined technical object. The optimally carried-out early stages of diagnostic examination should lead to the acquisition of magnetic information of proper quality and quantity. The acquired diagnostic information, when transformed accordingly, should enable us to reach the specific magnetic, electromagnetic or magneto-mechanical phenomena. The analysis of these phenomena [1,4,6], when combined with the information on the operating conditions and the state of a technical object, will lead towards finding the relevant diagnostic measure, which in accordance with the nature of magnetic methods, will describe the early phases of emerging defects.

To sum up, one of the significant problems encountered at the stage of work on the use of a magnetic field registered around the tested object in order to determine its technical condition turns out to be the right diagnostic information hidden in the magnetic field signal. Another problem is the separation of various coexisting effects, which affect the resulting distribution of the magnetic field and the proper presentation of the results.

The article addresses each of the above indicated issues. The second chapter presents the issues for the diagnosis of steel structures. The potential physical phenomena, associated with the magnetic signals that can contain diagnostic information related to the examined objects, are pointed out. The next chapter contains the description of the experiment and an example of its interpretation. The experiment is concerned with flat samples made of martensitic stainless steel 3H13 (X30Cr13[1]), which are in various degrees of effort. The results demonstrate the possibility of reaching new diagnostic information regarding the diagnosed object.

2. Theoretical background

The search for diagnostic information in increasingly diverse physical relations is a noticeable trend in modern technical diagnosis. Such innovative solutions can be sought among the so-called cross-effects, which are the relations between the canonic dimensions of a given form of energy and stressed dimensions of a different form of energy (see Table 1). In accordance with the assumptions presented at the beginning, the subject of these considerations is the use of a passive observer of state or change (signal) of a magnetic field for diagnostic inference about the steel structures with respect to mechanical/strength properties.

Due to the use of the concept of passive magnetic method for diagnosing the state of stress, the interesting cross-effects are concerned with mechanics and magnetism (the magnetomechanical effects), which have been the scope of research conducted by numerous scientists. In the 20th century, the phenomena related to steel were examined by Jiles and Atherton [1,9,16], as well as Robertson [20,22], among others.

By generalizing the observed effects as having the form of magnetic phenomena, it is possible to classify the type of information they carry, which includes information on the following:

- the subtle energy state of a material (the domain structure),
- the crystalline network deformations (structural and magnetic anisotropy),
- the microstructure of a material (non-homogeneity, phases, cracks).

Noting, that energy status of the material affects spatial arrangement of magnetic domains within ferromagnetic material and distribution of magnetic field surrounding the element under test, it should be considered straightforward to apply energy model. With the stress effected magnetization it is believed that the values of magnetic parameters of the material would change under influence of mechanical stress in reaction to external forces. This phenomenon can be explained

[1] EN 10088-2: 2005 Stainless steels. Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes