MAGNETIC METHODS IN DIAGNOSIS OF MACHINES AND INFRASTRUCTURAL OBJECTS – A SURVEY

Szymon GONTARZ, Stanisław RADKOWSKI

Institute of Automotive Engineering, Warsaw University of Technology
ul. Narbutta 84, 02-524 Warsaw, ras@simr.pw.edu.pl

Summary

In contemporary diagnostics non-destructive testing plays increasingly important role in diagnosis of state of technical objects. Thanks to its continuous evolution there emerge new techniques which are based on innovative ideas. Apart from evolution of such state-of-the-art techniques as video-thermography, it is the group of methods based on magnetic phenomena that deserves particular attention.

Against the background of non-destructive diagnostic methods (NDT), the paper presents magnetic methods along with their division into active ones, i.e. the method relying on the Barkhausen effect, and the passive ones, i.e. the magnetic memory method. The physical phenomena on which the above methods rely are presented and discussed. These include: magneto-elasticity, magneto-restriction, magnetic field dispersion caused by structural and mechanical non-homogeneities, Barkhausen's noise, etc.

The paper also presents the concept of development of a passive magnetic method and its use for analysis of technical condition of all types of objects made of magnetic materials. While relying on earlier analyses and the experiment, the paper presents Villary effect and the possibility of using it for acquisition of useful diagnostic information on early stages of development of dangerous conditions and defects.

Key words: internal stress, non-homogeneity of structure, passive/active diagnostic methods, non-destructive diagnostic methods, Villary effect detection.

METODY MAGNETYCZNE W DIAGNOSTYCE MASZYN I OBIEKTÓW INFRASTRUKTURY - PRZEGLĄD

Streszczenie

Nieniszczące badania w diagnozowaniu stanu obiektów technicznych odgrywają coraz większą rolę we współczesnej diagnostyce. Następuje ich ciągły rozwój, dzięki któremu pojawiają się nowe techniki opierające się na nowatorskich pomysłach. Oprócz ewolucji takich nowoczesnych technik jak wideotermografia na szczególną uwagę zasługuje grupa metod opierających się na zjawiskach magnetycznych.

W publikacji, na tle istniejących nieniszczących metod diagnostycznych, zostały przedstawione oraz dokonano podziału metod magnetycznych na aktywne tj. metoda opierająca się na efekcie Barkhausena jak i metody pasywne tj. metoda pamięci magnetycznej. Przedstawiono i omówiono zjawiska fizyczne, na których bazują wymienione metody; są nimi: zjawisko magnetosprężystości i magnetostrykcji, zjawisko rozproszenia pola magnetycznego wywołane strukturalnymi i mechanicznymi niejednorodnościami, szumy Barkhausena, itp.

Przedstawiono również koncepcję rozwoju pasywnej metody magnetycznej i wykorzystanie jej do analizy stanu technicznego dowolnych obiektów wykonanych z materiałów magnetycznych. Opierając się na przeprowadzonych analizach i eksperymencie, w pracy przedstawiono efekt Villary'ego i możliwość jego zastosowania do pozyskanie użytecznej informacji diagnostycznej o wczesnych fazach rozwoju niebezpiecznych stanów i uszkodzeń.

Słowa kluczowe: naprężenia wewnętrzne, niejednorodność struktury, pasywne/aktywne metody diagnostyczne, diagnostyczne metody nieniszczące, wykrywanie efektu Villary'ego.

1. INTRODUCTION

Non destructive testing in diagnosis state of technical objects plays more and more important role in contemporary diagnostic. Due to following and continuous evolution, new techniques bases on innovative ideas appear. Many materials that could cause real threat of the catastrophe caused by fatigue wear, exceeding stress limits or emerging of plastic deformation have magnetic properties that could affect the local magnetic field. This creates possibility to increase variety of non destructive techniques. Thus recently magnetic methods pay particularly attention. Additionally, having on consideration consequences coming from unforeseen architectonic construction crashes and technical objects break downs, it is necessary to progress of science in direction of technology for early phases of fault development detection.

As far as quite well known and applicable are active magnetic methods for condition monitoring, passive techniques which bases only on the existence of natural magnetic field of Earth becoming very attractive alternative.

In the paper, many non destructive technique (NDT) was mentioned and family of magnetic method was described. In parallel, the classification of those methods was performed. Moreover real world experiment was performed; using steel samples during the tensile test, without additional sources of magnetic field, generating by the magnetoelastic effect, changes in intensity of magnetic local field was registered. Also the experiment with artificial magnetic source was performing to examine the distribution of magnetic field in space. It was aiming to compare and proof the magnetoelastic effect.

Targets of this paper can determine by cognitive aim and also by utilitarian intention. Cognitive target is hire most important; it is a background for the future work and consists in test and description of magneto elastic effects, which could be useful in nondestructive magnetic method for level stress assessment of steel objects in industry. Bases on these informations, idea of new passive magnetic method for non-destructive methods of diagnostics was presented.

2. NON DESTRUCTIVE TECHNIQUES - SURVEY

2.1. Non-magnetic diagnostics methods

While referring to the current state of knowledge it is worth stressing that in the case of steel structures, concrete structures as well as machines, attention is now mainly focused on detecting faults and defects in the earliest stage of their development. The methods currently used for this purpose include: the acoustic emission method, dynamic methods (change of an object's dynamic response), x-ray methods, ultrasonic methods, thermal emission, extensometer method as well as the penetration method and the method of defectoscopy of gas leakage. In order to identify the strengths and the weaknesses of the currently used methods, one should look at several of their representatives.

2.1.1. Acoustic Emission

Acoustic Emision (AE) is a technique which involves registration of elastic waves which occur in materials due to release of energy by intermolecular bonds. Generation and propagation of flexible waves results from deformations, cracks and phase changes inside materials. The place of their initiation corresponds to the point in which the original structural bonds of a material are broken as a result of the load affecting a given structure. The frequency of an acoustic wave which emerges in a structure is within the ultrasonic range, which is from 20 kHz to 1 MHz. This method enables identification of location of the source of signal [1]. AE is a popular non-destructive technique and it enables tracking the development of intra-structural defects during use/operation of an object. The method is widely used in detection and location of defects in pressure tanks, pipelines and in detection of corrosion centers [2,3]. The drawback of the method is the difficulty in determining the extent of the defect and the remaining life of an object. Use of other NDE methods is recommended [4], such as radar surveys, visual checks, x-raying, in order to revise the findings. A separate issue is the ability to understand the acoustic emission signals due to the low power of registered diagnostic signals. Acoustic emission is a passive research method, since detection of an emerging defect is possible only when it is a source of a flexible wave. If, in given conditions of structure load, no deformations or phase shifts occur, then is impossible to detect a defect.

2.1.2. Dynamic methods

A new approach is being developed now for evaluation of the condition of structural elements, both the ones made of steel and pre-stressed concrete. It relies on changes of dynamic characteristics of entire structural elements under the influence of changes in the stress structure [5]. In to-date practice the dynamic response of a structure is used in non-destructive testing for the purpose of detection, location and defining of the degree of defect development. While defining a structural defect as a kind of deviation of geometrical and material-related properties, one can expect changes in the system's dynamic response to a pre-defined load. Use of such diagnostic information is important for two reasons. First, locating a defect and estimating its extent constitutes the basis for more detailed evaluation of the defect's importance.

In spite of numerous tests and the fact of obtaining many interesting results [6], still numerous issues which are associated with use of defect detection methods relying on vibroacoustic signals remain unsolved. These above all include the possibility of location and optimization of defects in the structures in which only several functions of proper (own) vibration are available as well as in systems characterized by complex dynamic structure; in a situation when we do not have the model vibroacoustic signal for the non-defective system or in conditions of high uncertainty as regards modeling, measurement and analysis of the obtained signal. These difficulties increase as attempts of defect identification are made in early phases of their development.

2.1.3. Ultrasonic method

Ultrasonic method is a non-destructive method during which the times elapsing between sending of an impulse and the first echo reflected from a non-continuity in a material and the echo reflected from the other side of the material are measured and compared [7]. The method has been developed extensively, with norms having been worked out which define the conditions for the method's application. Unfortunately no 100% certainty exists that the area of survey has been defined correctly. That is why it is best to supplement the method with a magnetic survey which can precisely locate the faults or the threats which emerge in the places where the object's faults exist. Combined use of the magnetic survey and the ultrasonic method enable most certain (the best and the most precise) decision as regards permitting an object for further safe operation.

2.1.4. Penetration method, thermal emission and flaw detection of gas leakage are further methods which should be presented from the point of view of their application for diagnosis of various technical objects.

The penetration method relies on the phenomenon of penetration of open surface cracks by liquids. It detects open surface discontinuities with widths starting from 10^{-6} m, e.g. fatigue-related cracks, grinding cracks, porosity, foliation, pinholes, cracks which emerged following forging or rolling, etc [8]. Only the surfaces of the objects are examined and in addition the faults detected with the use of this method are in many cases too developed to avoid a threat related to further operation of an object.

The thermal emission method relies on the thermo-elastic effect, that is a relation between stress and infrared radiation emission [9]. The temperature changes locally in a material, in the places where stress occurs due to the applied load. This method is used for measuring dynamic stress. However the method cannot be used to determine the directions of stress as well as internal stress, which substantially reduces its utility value.

Flaw detection of gas leakage is a non-destructive technique which, thanks to showing the movement of gas particles within the area of operation of the measuring probe, is able to locate the undesirable leakage in devices, joints, etc. The method is widely used in numerous industries, e.g. gas distribution, power engineering, aviation, petroleum industry, etc. It is a method for immediate and local use, a method which detects faults in their developed stage, which is a drawback when confronted with the present requirements set for state-of-the-art diagnostic methods.

2.2. Active magnetic diagnostics methods

As it turns out, the materials for which there exists a real threat of occurrence of a failure caused by material fatigue, exceeding of permitted stress or emergence of plastic deformations have magnetic properties, which enabled development of a group of magnetic methods in technical diagnosis. At present the group is already quite big and widely applied. The main methods representing this family of methods include: magnetic noise method (the Barkhausen method), eddy current method, powder technique and magnetic flux leakage method. While defining more precisely the classification of the above mentioned diagnostic methods, one should state that they include active magnetic techniques [10]. The specific nature of this group is the fact that magnetic field is applied to the material and variations in field parameters such as permeability, hysteresis and magnetic Barkhausen emission are used to draw inferences about the material stresses. Active magnetic techniques usually use high strength, low frequency fields to drive the material into saturation so as to offer fairly good penetration.

2.2.1. Barkhausen method

This method is used for dynamic tests of features of a magnetic structure which is associated with the state of a material [11]. It also enables determination of the distribution of own stress of the outer layer depending on depth. The limitation of this method is the difficulty associated with the analysis of information concerning the type of the examined stress which is contained in the registered signal. The Barkhausen effect signal is an electromagnetic signal with a wide range of frequency and characteristics similar to noise. Thus its analysis is complex while the results of the analysis are uncertain.

2.2.2. The magnetic flux leakage measurement method (MFL) [12] works as follows. The examined tendon is magnetized by exciting a magnetic field $H_0(p,x-x_0)$, which is normally generated by a movable yoke-magnet. $x_0(t)$ denotes the actual position of the yoke-magnet; p describes the amount of the exciting field, which depends on time (i.e. on the step in the scheme of magnetization of components). The exciting field generates magnetization $M(x,x_0)$ in the ferromagnetic components of the reinforcement. Local disturbances of magnetization, due to ruptures or reduction of cross-section, result in typical magnetic leakage signals. The magnetic flux leakage measurements can be performed during magnetization (active field measurement) or as residual field measurement after a special sequence of magnetization of a member.

2.2.3. Electromagnetic methods, magnetic powder technique and eddy-current methods are further active magnetic methods which find use in modern diagnosis.

The common characteristic of a wide range of electromagnetic methods is the use of effect of induction [13], under the influence of outer electromagnetic field or variable electric currents. The currents cause emergence of secondary magnetic field. Measurement of the primary (outer) and the secondary magnetic field enables one to infer about an object's properties.

Magnetic powder technique [14] is a nondestructive technique which is realized in order to find discontinuity on the surface and also close under the surface of ferromagnetic materials. It is a very fast and reliable technique of discovering and locating, e.g. cracks in a surface. Magnetic flux passes through the material. Magnetic leakage occurs in the place of discontinuity, which attracts molecules of metal from the alluvial powder.

Eddy-current method [15] is a nondestructive investigation method which relies on measurement of change of induction current in ferromagnetic materials, which depends on the amount and the size of material discontinuity in the zone which is subjected to a probe. This method allows finding the defects on the material's surface and under its surface, up to the depth of about 0.6 - 1.0 mm.

As can be seen from the descriptions, no single, comprehensive method exists which would enable clear-cut assessment of technical condition of the examined object. The methods which are dominant on the market are usually restricted to detection of local defects, such as cracks, material non-homogeneity or plastic deformations, and they call for interaction with their user. In addition, while taking into account the task of control and measurement of stress and deformation in devices or structures, the following shortcomings are discovered:

- the methods cannot be applied to plastic deformations;
- they are local, useless in the case of extensive structures;
- they do not allow assessment of the changes in the material's structure;
- they require samples to be prepared up-front;
- they require that surfaces be prepared for tests;
- the above magnetic methods require artificial magnetization of the examined element;
- it is difficult to define the areas of stress concentration.

Moreover, it is worth noting the differences that directly result from comparing the distinguished magnetic methods and the remaining NDT methods:

- the magnetic method is a technique of diagnosis of fatigue-related defects in the phase of their emergence and development;
- during the magnetic test, apart from early fault detection we also obtain information on the actual status of stress and deformation of a material as well as on the reasons of propagation of defects.

The above listed differences are undoubtedly new and very useful features which cannot be achieved by other diagnostic methods. Magnetic tests can prove to be the basic diagnostic technique applied for locating changes in objects, in the structure of materials but unfortunately only in the materials with magnetic properties. In spite of this drawback, in parallel with development of active diagnostic methods we also see the development of a group of passive diagnostic methods which has all the advantages of active methods but at the same time does not require use of artificial sources of magnetic field, which is connected with use of complex and costly apparatus.

3. PASSIVE METHOD DESCRIPTION – CORESPONDINGS EFFECTS

The existence of the Earth's magnetic field is the basis for using passive magnetic methods. The Earth can be considered to be a homogeneously magnetized globe, having magnetic axis with south pole in the northern geographic hemisphere and magnetic north pole in the southern hemisphere. It is obvious that, every "physical substance" staying within the magnetosphere will have influence on the local magnetic area of earth, but the influence will vary, depending on the material of which a specific object is made. Taking into consideration the materials which are of interest to us, one must say that different types of steel can be both magnetic and non-magnetic (magnetic metals: cobalt alloy, iron, nickel alloy, steel (except stainless steel); non-magnetic metals: aluminum, brass, cooper, gold, silver, titan, stainless steel).

When the stress changes in materials with magnetic properties, then transformation of a material to magnetic state proceeds – it can be found in magnetic memory metal (MMM) or in residual magnetic field (RMF). In general one could certify the existence of a relation between stress and degree of magnetization, but it is a complex task because additionally it depends on the type of magnetization, history of magnetization, strain and temperature. These properties have been used to create passive diagnostics methods.

3.1. Magneto acoustic method

One of the popular techniques is magneto-acoustic emission for state diagnosis of microstructure of exploited ferromagnetic steels. It commonly use with external source of magnetic field but it is also consider as a passive magnetic method [16, 17]. As it turns out, Barkhausen phenomenon is accompanied by emission of an acoustic wave, which is termed as the magneto acoustic effect. The acoustic wave is much less susceptible to damping then the Barkhausen effect's signal. This can be exploited to obtain information on the status of stress deep inside the magnetized area. A serious drawback is lack of monotony of dependence of intensity of acoustic emission on stress, which restricts the research related to exploiting this phenomenon. So far the results show that for ferritic-pearlite and pearlite–bainite steels the method which relies on the magneto acoustic effect is characterized by very good properties from the point of view of non-destructive investigation techniques. The valuable property of this method is the intensity of magneto acoustic emission, which becomes monotonic for these steels and the strongly diminishing function of degradation grade, present already at the very early stage of the degradation process (before the defects of microstructure appear). In the case of magneto acoustic method, it is the effect whose intensity is the sum of the emission occurring in the whole magnetization area. Such properties of both effects result from considerable damping of electromagnetic waves in the metal and from the relatively insignificant (as compared to electromagnetic waves) damping of acoustic waves. Such a conclusion demonstrates that magneto acoustic method is particularly useful for nondestructive testing of 'heavy-walled' elements.

3.2. Magnetic memory method

Another interesting passive magnetic method for non destructive techniques was developed in Russia. It is a diagnostics method for products and machines which is based on magnetic memory effect in metal. The conditions of forming of magnetic residue in metal were specified, while reflecting structure of memory and condition of intensities and strains of object. This technology was given the name of Magnetic Memory Metal (MPM) [18] and it is based on the physical phenomenon of magnetic-elasticity, magnetostriction and their relation to creating and locating the limit of magnetic domains on wall of dislocation in concentration zones of intensity and on phenomenon of magnetic dissipation which causes by structural and mechanical heterogeneities in condition of natural magnetization made by the load.

Magnetic parameters which are useful in MPM testing:

- normal component of intensity dissipation of magnetic field - Hpy;
- gradient of magnetic field (dHp/dx) for distance x.

Based on the above parameters, it is possible to define concentration zones, in which forming incipient developing faults, damages of structure in concentrations zones and heterogeneity of metal. During tests with MPM, natural magnetization in the Earth's magnetic field is used. The probes placed on the surface of the tested element register a component which is perpendicular to the surface of intensity magnetic field Hpy. The analysis of the results obtained from the measurement concerns the qualitative change – change of sign, and quantity change - change of Hpy value. Based on this research, the assessment of intensity and strains as well as on discovering the concentration zones' intensities is possible.

A quantitative parameter has been elaborated for measuring the concentration of stress. In MPM it is called the magnetic intensity factor of stress and it is determined as a gradient of vertical component of dissipation magnetic field on a fixed path, close to the perpendicular line crossing the stress concentration line.

$$K_{in} = \frac{\left|\Delta H_p\right|}{2 \cdot l_\sigma} \tag{1}$$

K_{in}- stress intensity factor

H_p – vertical component of eigenmagnetic field

l_σ –fixed path near the perpendicular line crossing the line of stress concentration.

Summing up, the method of magnetic memory enables estimation of condition of stress and strains while taking into consideration the heterogeneity of the structure, both in terms of elasticity as well in terms of plastic strains. The method does not offer specific information about level of fault, but it allows distinction between the strains elasticity zone and plastic strains zone. If a crack already exists, method will allow determining the extent and the direction of the crack's development.

In general the group of passive magnetic methods is considered to be very promising and modern techniques of the 21st century. Compared to active methods, these methods have many advantages as they do not need any artificial source of magnetic field and thus they can be used not only for diagnostic tests but also continuously, for example in condition monitoring. This feature also allows their use in places where artificial sources of magnetic field could be dangerous. The passive methods do not require any preparations of the object and they can be used even in places to which access is difficult. For this and for other reasons it is worth developing this branch of diagnostic methods.

4. CONCEPTION OF NEW PASSIVE MAGNETIC METHOD

In general each magnetic method consists of exploiting the diversity of magnetic properties of the elements of a physical medium in the earth's or artificial magnetic field. When the quality (the method) of influence of the magnetic field and the effects of such influence on the examined object are taken into account, then the magnetic method of analysis of technical objects can be proposed. The aim of this method is to detect dangerous conditions of stress and deformation. The proposal seems to be correct when the evolution of magnetic methods is taken into account, and it seems indispensable in diagnosis of such objects since, as the statistics demonstrate, the known methods and techniques of technical condition analysis are insufficient to ensure full safety of use.

The proposal concerns use of the magnetic method for the purpose of detection of early phases of development of dangerous technical conditions as well as for defining the boundary conditions which can lead to a catastrophe or failure. The benefits of applying such a method can be invaluable.

Every "physical body" located within the magnetosphere has influence on the Earth's magnetic field in accordance with relevant mechanisms which are known in physics. The outcome of these changes is but one, that is these bodies (objects) can increase – in a varied degree – the density of the lines of magnetic field's power (they can increase the intensity of the field) or they can deflect the lines of the field's power away from the sample (they can decrease the intensity of the field). Analysis of magnetic phenomena in various publications has led us to the conclusion that an object's own magnetic field:

$$H = -\nabla(w) \tag{2}$$

where 'w' denotes the magnetic potential, is the function of the gradient of magnetization M:

$$w = w\ (\mathrm{div}\ M). \tag{3}$$

Own magnetic field of object H, e.g. measured by a magnetometer, depends thus on the object's magnetization and distribution of this quantity in space. In addition, while bearing in mind the magneto-mechanical phenomena, it turns out that if the stress is changed in materials having magnetic properties, then the material is transformed into magnetic state. This phenomenon is described by the Villary effect, also called the magneto-elastic effect which is a reverse phenomenon to magnetostriction. It involves change of intensity of the magnetic field (or of magnetization) under the influence of mechanical forces applied to a material, with the forces introducing stress to the material, and it includes transformation of the mechanical energy associated with deformation of the material into magnetic energy. In general one can conclude that there exists a quantitative change which describes relation between stress and degree of magnetization, and additionally there exists a qualitative change of magnetic permeability which is associated with the fact of reaching the condition of plastic deformations. This offers the possibility of obtaining new, extremely valuable diagnostic information on the degree of effort of the structure. The relationship we are interested in looks as follows: M=M(stress, plastic deformation). Assuming that the only magnetic field which will influence the object will be the Earth's magnetic field, then it can be clearly seen that the factor shaping the object's magnetization is the object's magnetic permeability μ, which for a given material is not constant and which depends on the above mentioned magneto-mechanical phenomenon.

An experiment was conducted: while using the samples made of steel designed according to our own needs, and then subjected to stretching without any additional sources of magnetic fields, we registered the changes in the intensity of the local magnetic field which were generated by the so-called Villari effect. The changes of the magnetic field were collected by a three axial fluxgate magnetometer. First configuration was investigating four different distances (25, 50, 100, 150 [mm]) (Fig. 1) from one sensor (the second one was stable) in a function of magnetization. During the test the load was changing from 0 to about 50% of force for Re.

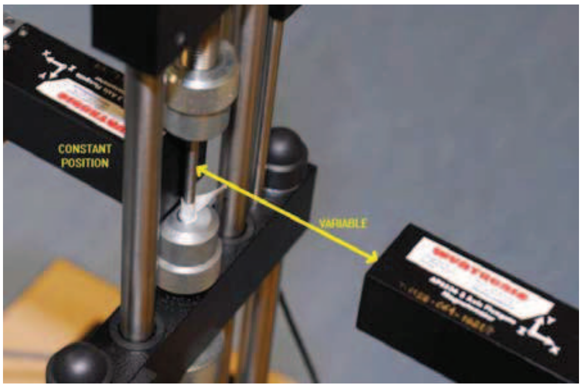

Fig. 1. Magnetometers configuration strategy

Based on the results (Fig. 2), it is easy to observe the change of magnetic field intensity which varies along with the change of the distance between the sensor and a specimen. It is important that the range of the change varies depending on measurement direction. So, the measurements performed by the three-axial fluxgate magnetometer allow exhibition of own magnetic field component (vertical direction) which is least sensitive to disturbances (magnetic field of environment) that are present in the real world and allows determine this direction as the most informative for stress assessment [19]. It is worth noting that in spite of the small size of the sample (sample diameter – 6mm), it was possible to observe the change of the magnetic field as caused by Villary effect, even from the distance of up to 100mm.

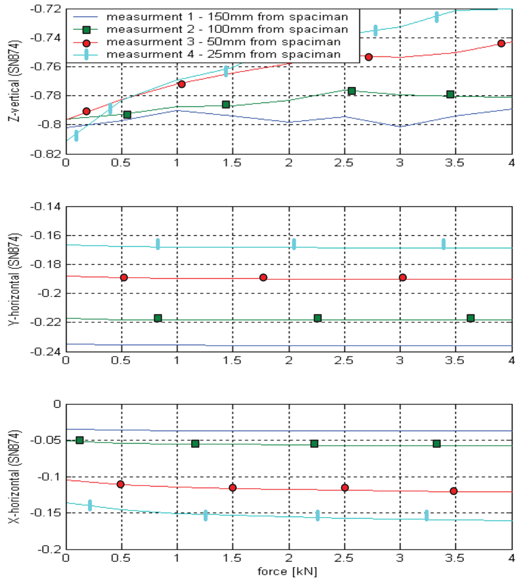

Fig. 2. Change of magnetization (in Gauss) in a function of force with different measurement distance

During the next stage of the test, the real specimen was replaced by the artificial source of magnetic field – an electromagnetic yoke. This enabled discovering the distribution of magnetic field's source in space. The intensity of the magnetic field was decreasing exponentially, which is presented in Figure 3.

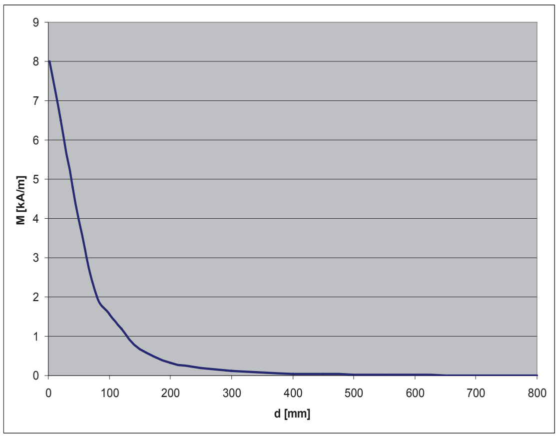

Fig. 3. Distribution of magnetic filed along the horizontal direction from the specimen

The conducted research has demonstrated the existence of magnetoelastic phenomena for the designed samples. We have proven that the qualitative change of the magnetic field occurs in a situation when a sample subjected to stretching interacts with the surrounding magnetic field, and such a change is similar to the change of the field in a situation when the electromagnetic yoke is the source.

The tests have demonstrated that without using any additional external source of magnetic field it is possible to describe the state of prevailing mechanical stress, with varied correlation between the values of the magnetic field's components and the intensity of the generated magnetic field which depends on the direction of measurement.

The issues which have been analyzed here give hope that the method of passive magnetic diagnosis, which relies on quantitative and qualitative change of own magnetic field of an object, can offer a new possibility of detecting the early phases of hazardous conditions in technical objects. Few steps were made to get closer this opportunity [20, 21].

5. CONCLUSIONS

Further work related to development of the magnetic technique, which allows early fault condition detection in technical objects made of ferromagnetic materials, should be carried on. Exploiting the fact that without the use of additional external sources of magnetic field there exists a possibility of presenting the estimates of mechanical stress condition, with the correlation between the intensity of the changes which generate magnetic field depending on measurement direction, creates a possibility for rise of a new universal and efficient diagnostic method. The paper points out that innovative passive magnetic technique, which rely on quality and quantity changes of magnetic field, can bring good results to diagnosis of complex technical objects.

By controlling the plastic and the elastic range of specimen deformation, we have proven the existence of a relation between stress and magnetization degree, which is strictly connected with deformation and degree of effort. In our test three perpendicular directions were used, which clearly shows that changes of magnetization arising from the mechanical stress differ depending on the measurement direction. Additionally, the distribution of the eigenmagnetic field generated by a tensioned steel object offers hope for a possibility of remote stress assessment but the measurement settings should be properly chosen. In such a situation the properties of the technical object, for example the material, shape, structure and dimensions should be taken into consideration.

The paper was prepared on the basis of researches conducted within a project „Monitoring of Technical State of Construction and Evaluation of its Lifespan" (MONIT). Project is co-financed by the European Regional Development Fund in the Operational Programme Innovative Economy (PO IG 1.2)

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Szymon Gontarz, M.Sc., a Ph.D. student in SiMR Department of Warsaw University of Technology.
In his scientific work he deals with vibroacoustic analysis, security of technical systems, signal processing and non destructive techniques for technical diagnosis.

Prof. **Stanisław Radkowski**, a professor in Institute of Institute Automotive Engineering of Warsaw University of Technology, manager of Laboratory of Automotive Mechatronics System. In his scientific work he deals with vibroacoustic diagnosis and technical risk analysis.