Applied Physics Research; Vol. 4, No. 3; 2012
ISSN 1916-9639 E-ISSN 1916-9647
Published by Canadian Center of Science and Education

A New Electromagnetic Technique for Controlling Stress in Metals

Nedal A. M. Altawalbeh[1], Saed A. Al-Thuneibat[1] & Melad M. Olaimat[1]

[1]Electrical Engineering Department, Al-Huson University College, BAU, Irbid, Jordan

Correspondence: Saed A. Al-Thuneibat, Electrical Engineering Department, Al-Huson University College, BAU, Irbid, Jordan. E-mail: Thuneibat@Hotmail.com

Received: February 3, 2012 Accepted: February 26, 2012 Online Published: July 16, 2012

doi:10.5539/apr.v4n3p48 URL: http://dx.doi.org/10.5539/apr.v4n3p48

Abstract

Theoretical investigations of the magnetic field, in the cores of rectangular cross-section, based on the nonlinear characteristics of the ferromagnetic materials, are presented in this paper. Moreover, the mathematical model of the field solved by iteration. This paper aims to investigate how to control the stresses in metals. Specifically, it aims to determine the relations between the parameters of metal hysteresis loop and topography of scattering field.

Keywords: force of coercively, field of magnetic part, information parameter

1. Introduction

Mechanical engineering enterprises, metallurgical, aviation and other industries produce mass batches of products, made of ferromagnetic materials (steels and cast irons). The mechanical behavior of materials depends on their response to loads, temperature, and the environment. In several practical problems, the combined effects of these controlling parameters must be assessed (Robert, 2005; Wole, 2003). The designed phys-mechanical properties of which are reached by the definite regimes of thermal treatment, tempering, hardening and other conditions. Possible deviations of the regimes, from thermal treatment of products may lead to unacceptable changes of mechanical properties, which require the control of all the output. However, as a results of the products use, these deviations can also arise. It is well-known that, at present there are a considerable number of machines and constructions that being used, while, the rated service life has already been expired. Long-term service of a large stock of working metal constructions, without its control criteria and standards, determining the service reliability of metals, and as a result, forecasting of service life and determining the safety margin of elements of a construction, may be dangerous. The serviceability of machines parts is limited, because of the accumulation of internal stresses in them during service time. These internal stresses are stipulated by long-term attacks of mechanical and thermal loads and corrosive media as well. Under the action of these factors, the internal structure as well its mechanical properties will change.

One of the most reliable nondestructive testing methods of phys-mechanical properties, and structure of ferromagnetic materials and products made of them, is the magnetic one (Robert, 2005). It is an application in machine manufacturing, which, especially, appears as a direct method of determining phys-mechanical properties of steel. Which are destructive and can't be used to determine the quality of products, made for service. Actually, in an attempt to performing more comprehensive magnetic analysis making a laboratory test specimen of structure parts is required, which, is not always convenient for conducting research.

The problem of determining the state of stress of construction members made from ferromagnetic materials using nondestructive testing is a challenge and has both scientific and applied importance (Emel'yanov, 2008). Indeed, physical principle of the magnetic method is the fact both phys-mechanical and magnetic properties of steels are sensitive to the changes taking place in the phase, chemical constitutions, structural and stressed states of steels and alloys (Agrebelniy, 1999). The methods of structural phase analysis and of nondestructive testing developed by the present moment make possible testing of metals structure and properties without test specimen as well as their changes during plastic deformation. These methods use correlation between structural parameters of steel (and hence its mechanical properties) and some magnetic characteristics.

2. Theoretical Consideration of Calculation

In this section of research, we introduce the magnetic characteristics of substance which are used in the calculation method. Section 2.2 represents the dependence of metal parameters on the observation point.

2.1 The Magnetic Characteristics of Substance

The first experimental measurements of variations in magnetic parameters of electric steels were obtained by Yanus and Vonsovskii in 1938 (Korzunin, 2001). Nondestructive testing of structure and mechanical properties of steel product usually uses the magnetic characteristics of substance. The following are the widely used characteristics:

- Coercive force (quality control of hardening, annealing, low-temperature tempering of parts made of carbon and low-alloy steel, mechanical properties of rolled steel, depth and hardness of surface strengthened layers H_c on parts etc).
- M_s: Saturation magnetization (quality control of hardening of the bearing steels & the quantity of the retained austenite).
- M_{Hf}: Relaxation magnetization (magnetic induction B_H).
- X_H: Magnetic susceptibility (permeability μ_r).
- The initial μ_H and maximum μmax magnetic permeability's (susceptibilities χ_H and χ_{max}) are also used for solving some tasks.

In some cases, nondestructive testing with one magnetic characteristic can't be carried out. It is advisable to use multi-parameter methods during quality control of hardened bearing elements, cold rolls, margining steels, rolled steel mechanical properties using some of the mentioned parameters above. The nature of relationship between magnetic properties, obtained on the magnetization curve and on the limiting hysteresis loop, structure and phase constitution of different classes of steel after hardening and tempering had been studied in details.

2.2 The Dependence of Metal Parameters on the Observation Point

The operation of the majority of modern instruments used for magnetic structural analysis is based on the measurement of the magnetic properties of the body (Kostin, 2004). The research of application of nondestructive methods of testing carried out in institutes and industry made it possible to reveal the magnetic parameter – coercive force, which correlates with stressed and deformed state of large metal structures, when the correlation coefficient can be r = 0.9 and higher.

The availability of stable correlation's according to the value of coercive force H_c allows to control the level of plastic deformation $\varepsilon_{p\lambda}$ and forecast remnant service life of metal constructions during operation.

It is typical that value H_c remains constant and equal to H_c^0 for all types of steel during loading till reaching yield limit $\sigma_{0,2}$ by metal (Musikhin, 1984). After going to the elastic and plastic state H_c linearly rises up to failure when the value $H_c^{critical}$, which is equal to metal ultimate strength σ, is reached. In this case, the accumulation of residual plastic deformation begins when metal reaches the yield limit. And thus the accumulation takes place according to the exponential law up to the failure.

The quantitative characteristics of curves $H_c(\varepsilon)$ also depend on whether deforming stress is compression or tension. After the deformation by tension the coercive force of hardened steels H_c decreases more considerably than after the deformation by compression. Value H_c does not almost change or slightly decreases when compression or tension take place, the deformation being in the region of ε =8 –16 %. H_c of tempered steels changes in the opposite way when these steels are subjected to plastic deformation. H_c rises when the deformation is up to 4%, and it rises more sharply after the deformation by compression. H_c remains practically unchanged when ε rises from 4 to 16%. Only when the degree of deformation is much higher it rises slightly.

Besides the coercive force, many information on metal state can be obtained. By studying the parameters of dependence of the components of stress vector of scattering field of the magnetized part of ferromagnetic product on the coordinate of linear displacement of the point of observation as related to the magnetized part as shown in Figure 1.

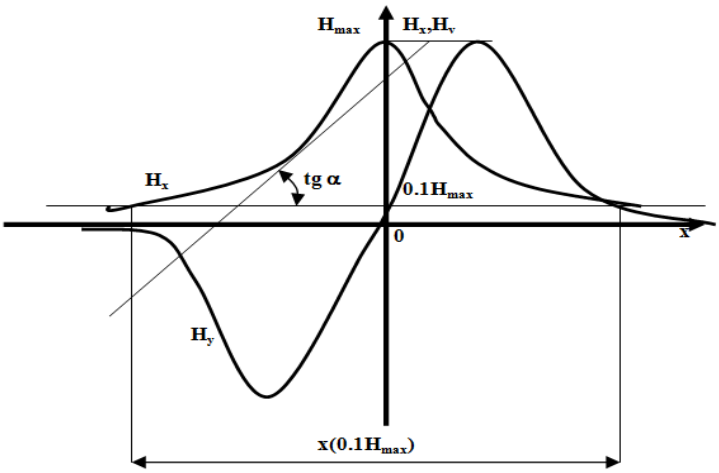

Figure 1. Dependence of ferromagnetic product parameters on the displacement of observation point

Information parameters of this dependence include:

- amplitude (the maximum value of stress vector components) H_{max};
- tangent of characteristic (tg()),
- extent of scattering field 0.1 H_{max}.

The magnetic way of determining mechanical stresses in hot-rolled reinforcement has been known (Pekker, 1965), it allows estimating the margin of reinforcing-bar steel strength according to the parameters of component of magnetic field stress, this magnetic field being measured with Hall generator. The idea of the method can be extended to include the control of magnetic state of metal constructions of transport vehicles, cranes, bridges, etc., which are in the loaded state.

This paper aims at the theoretical ground of the method of obtaining data for determining relations between the parameters of metal hysteresis loop and topography of scattering field.

As the physical state of ferromagnetic material correlates with its magnetic characteristics, the connection between the parameters of scattering field of the magnetized part and physical state of this part of metal will be determined.

3. The Calculations of the Scattering Field of the Magnetized Part

The calculations of the scattering field of the magnetized part are performed in the following sequence:

1) to determine the field of the magnetization vector ∏ - shaped electromagnet (**a** =120 mm) in the non-linear electromagnetic medium;

2) to calculate the vectors of intensity of scattering field $\bar{H}(Q)$ of the magnetized part in air space by the solution of the integral equation:

$$\bar{H}(Q)=\frac{1}{4\pi}\left[\sum_{j=1}^{N}\sum_{v=1}^{6}\left(\bar{M}_j\,\bar{n}_j\right)\int_{\Delta S_v}\frac{\bar{R}}{R^3}dS\right]+\bar{H}_0(Q) \tag{1}$$

Where

$\bar{H}_0(Q)$– Field intensity, generated by the coil of the magnetizing device;

$\bar{n}_j$ – External normal to the surface S in integral point;

$\bar{R}$ – Radius vector connecting observation point Q with current integral point;

N – is the number of volume elements, into which the equation solution is divided;

ΔSv- is the surface of v –face, j - volume element;

Mj-is the magnetization vector in the field of ferromagnetic material;

3) to find the information signal of a magnet measuring channel the above-mentioned formula, in which magnetization is considered to be the known value;

4) to change the parameters of hysteresis loop of the magnetized material in the second quadrant and to repeat the calculations procedure.

Figure 2 shows the magnetized structure and scattering field of the magnetized part. The calculations of magnetic field have been performed according to the method given in (Pekker, 1965) with the algorithm of iterative solution of the system of the integral equations suggested in (Romanenko, 2000).

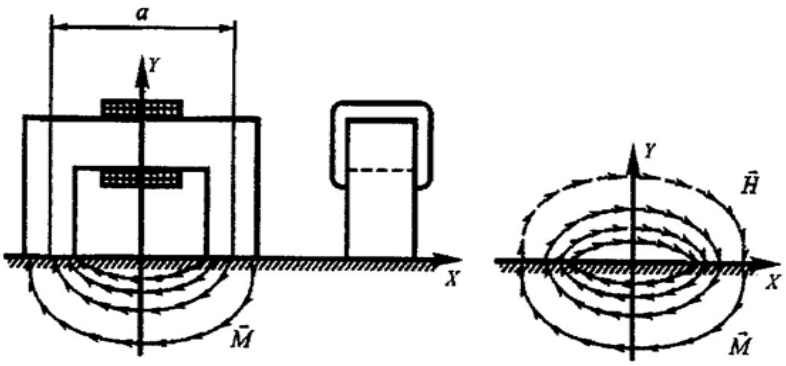

Figure 2. Magnetized structure and scattering field of the magnetized part

The solution of the equation (1) has been performed for different degrees of deformation of "the back" of hysteresis loop, as shown in Figure 3. Three measurements of coercive force (2500, 2750, 3000 A/m) and residual induction (1,12; 1,2; 0,8 T) have been carried out.

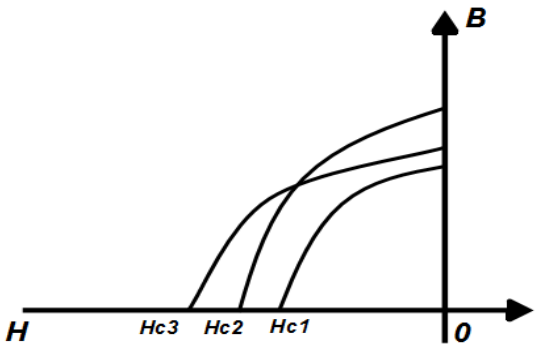

Figure 3. Deformation of the curve of demagnetization of a magnetic material

The processing of the calculation has been performed for single integral information signals. The solution of such problems is well-known and includes the following stages:

- the choice of generalized form of the components of scattering field intention;
- the discrete change of the form of "the back" of hysteresis loop with the aim of formation of standard dependencies *Hx(X), Hy(y)*;
- The reveling of information criteria entirely characterizing every library component and considerably reducing the volume of the saved information on the components of the field intention vector;
- The description of the calculation process which results in the construction of the series of discriminate functions, the stage of classification of scattering field intention function and the decision about its correspondence to the nearest standard.

Figure 4 shows spectral portraits of information signals, characterizing the dependence of topography of scattering field on parameters *Hc, Br*. It is evident from Figure 4 that the analysis of coercive force values according to integral characteristics of components of scattering field of magnetized parts can be carried out.

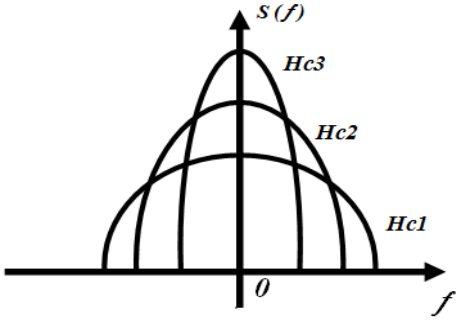

Figure 4. Spectral portraits of information signals depending on H_c

4. Conclusions

The methods of structural phase analysis of nondestructive testing, developed by the present moment, make possible testing of metals structure and properties without test specimen as well as their changes during plastic deformation. These methods use correlation between structural parameters of steel (and hence its mechanical properties) and coercive force, saturation magnetization, relaxation magnetization, magnetic susceptibility initial and maximum magnetic permeability as magnetic characteristics.

References

Agrebelniy. (1999). Magnetic Control of Stained-Deformed State of Welded Connections and Steel Metal Constructions. *Technical Diagnostics and Nondestructive Control, 13*(4), 45-52.

Emel'Yanov, I. G., & Mitropol' Skaya, S. Yu. (2008). Determination of Matrix Dependences between the Magnetic and Elastoplastic Characteristics of steel during Tension. *Russian Metallurgy, 2008*(2), 168-173.

Korzunin, G. S., Chistyakov, V. K., & Rimshev, F. F. (2001). Developing Techniques for Magnetic Properties of Electric Steels. *Russian Journal of Nondestructive Testing, 37*(4), 239-262. http://dx.doi.org/10.1023/A:1012308204987

Kostin, V. N., Osintsev, A. A., Stashkov, A. N., & Tsar'kova, T. P. (2004). Multi-parameter Methods for Structural Analysis of Steel Articles Using the Magnetic Properties of Substances. *Russian Journal of Nondestructive Testing, 40*(3), 197-208. http://dx.doi.org/10.1023/B:RUNT.0000040178.84848.54

Musikhin, S. A., Novikov, V. F., & Borisenko, B. N. (1984). About usage of coerieve force as an indicating parameter in nondestructive control of mechanical strains. *Detectoscopy, 2*, 92-94.

Pekker I. I. (1965). Conduction of magnetic systems by the method of integration according to field sources Electromechanics. 484- 487.

Romanenko, A. V., Yakovenko, V. V., & Miroshnikov, V. V. (2000). Calculation of Magnetic permeability into ferroprobes when they are mutually influenced. *Methods and ways of nondestructive control, 6*, 6-8.

Robert, E. Newnham. (2005). *Properties of Materials.* New York: Oxford University Press Inc.

Wole, Soboyejo. (2003). *Properties of Engineered Materials*. NewYork: Marcel Dekker, Inc.