716. Mechatronic system for technical diagnostic using Barkhausen effect

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Abstract. The aim of this paper is to present the mechatronic system for technical diagnostic based on magnetic Barkhausen noise analysis. Intended use of this system is especially residual stress control with crack prediction or subsurface layer microstructure investigation of flat parts of machineries and constructional elements. The basis of Barkhausen noise inspection methods, fields of applications, construction of the investigation apparatus and details of measuring head positioning system were described. Horizontal setting of the head was realized with the step motors. The vertical lifting and lowering is controlled by pneumatic system. Open structure of the system let to use for control and data acquisition the standard PLC controllers.

Keywords: Barkhausen noise, diagnostic system, residual stress.

Introduction

Remagnetization process of ferromagnetic materials is associated with the cyclic conversion of their domain structure, consisting of re-orientation domains and moving their borders. As a measurable effect, of discovered in 1919 by Henrich Barkhausen phenomenon of discontinuous domain walls movement under the influence of external magnetic field changes, are local fluctuations in the magnetic flux [1]. Thus this induction flicker may be detected as characteristic, of so-called voltage signal Magnetic Barkhausen Noise - MBN, which will generate in a coil, placed on the surface of magnetized ferromagnetic materials (Fig. 1).

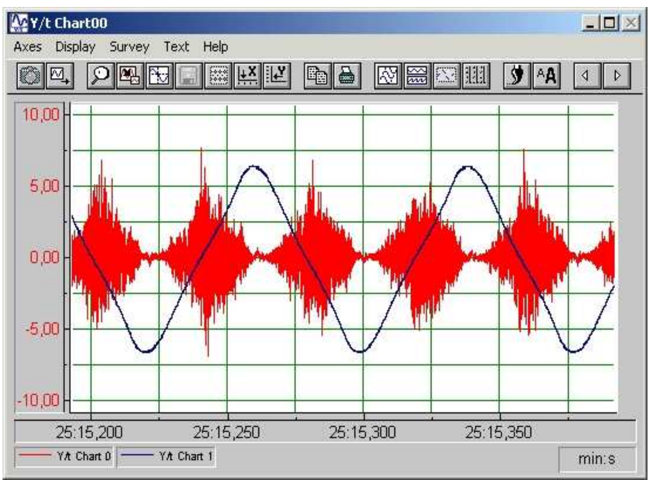

Fig. 1. Example MBN oscillograms with sawtooth wave of magnetization current

Course of Barkahusen effect and the electrical and geometrical parameters of the MBN, depends largely on three factors [2]: microstructural construction (type of microstructure, ferrite grain size), the state of internal stress (eg residual stress) and the state of magnetization of the investigated material.

The first two of these factors are among the basic parameters to be controlled in the technical diagnostics of machines, appliances and construction. Especially important diagnostic knowledge has experimentally verified state of stress, and indirectly inducing the stress strains. This allows determining, for example, the internal forces in elements of structures under operating loads and thus estimating the carrying capacity for additional loads.

Also, thanks to early detection of outbreaks of stress accumulation in the elements of machines and equipment, potentially leading to losing the continuity of the material and the initialization of cracks, allows the identification of states of emergency and prevent the dangerous consequences of accidents and disasters.

Measurement of residual stresses using the Barkhausen phenomenon (so called Barkhausen method) is done by measuring and comparing with the previously prepared calibration curve, one of the parameters of MBN - most often of its RMS value or number of Barkhausen jumps with amplitude above a specified voltage, counted per unit time in function of applied stress.

By contrast, the studies of the microstructure using this method are mainly based on the analysis of properties of geometric and time dependences of MBN envelope [3].

Barkhausen method has currently several applications: eg in the diagnosis of faults in the blades of aircraft engines [4], assessing the quality of welded joints [5], the study of distributions of residual stresses in structural shapes and pates [6, 7, 8], the diagnosis of the degree of degradation of steel in power plants, diagnostic tests of stress concentration in the mill's rolls [9], measurement of retained austenite, burning defects, the degree of wear of bearings [10].

These examples represent only a small part of a wide field of science and technology, where this method is applicable. This area, along with the development and improvement of this method of measurement, including the automation of the process and measurement, is constantly expanding.

This article presents a mechatronic system for automatic technical diagnosis, using as a carrier of information, magnetic Barkhausen noise. It is intended for stress testing and inspection and evaluation of the microstructure in the flat parts of machines and structures made of ferritic steels. This system allows minimizing the human impact on the measurement of the Barkhausen phenomenon, and significantly increases the efficiency of the diagnostic process based on it.

Testing system characterization

Manual handling the measuring head during the testing by Barkhausen method involves several disadvantages and inconveniences. For example, not apposition the measuring head at right angles to the test element, in its contact with the yoke, may increase the air gap. The immediate effect of this is change of the magnetization conditions, significantly affecting on the level of MBN generated.

Moreover, doing the diagnostic testing or examination of parts with large surface area, there is a need to perform a significant number of measurements with constant resolution. Making such measurements by hand is arduous and time-consuming and keeping the same spacing between measuring points is almost impossible, without the application of coordination grids.

To eliminate mentioned above disadvantages, by the mechanization and automation of lifting, lowering and repositioning the measuring head, in Institute of Modelling and Automation of Plastic Working Processes at Czestochowa University of Technology, special automated system for technical diagnostic based on Barkhuasen phenomenon was elaborated. It also enabled automation of saving operation the measurement results. Details of its construction (Fig. 2) and operating was widely presented in [11]. It consists of the Barkhausen noise measuring equipment [12] shown in left upper corner, complemented by an electromechanical

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system of positioning of the measuring head, computer-based automatic control system of measurement and data acquisition and registration.

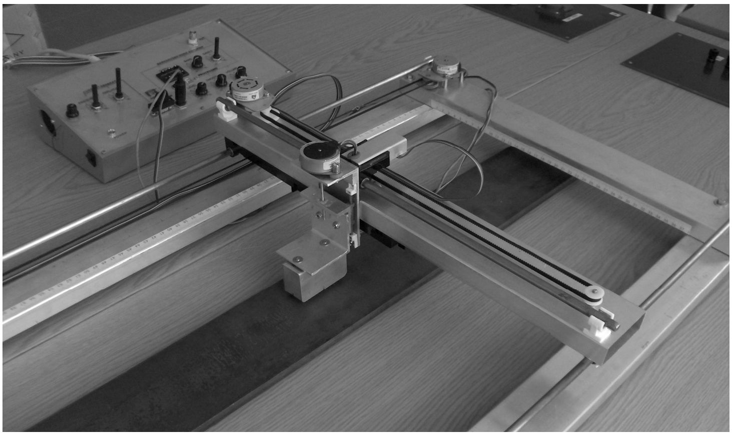

Fig. 2. A view of positioning device and measurement unit during operation [11]

Electronic test apparatus

To take full advantage of diagnostic information contained in the Barkhausen signal is needed appropriate measuring equipment, enabling both its excitation and detection and determination of its electrical parameters. Custom design of this electronic measurement equipment has been developed through the work on new methods of measuring the stresses [12]. In contrast to the currently dominant trend of virtualization measuring instruments, developed apparatus was in a way that the hardware implements most of test functions. This allowed the practice to become independent of hardware for data acquisition and specialized software for control & measurement. Block diagram of the apparatus was shown in Figure 3. It consists of three main blocks: magnetization, measurement channel and processing of MBN parameters.

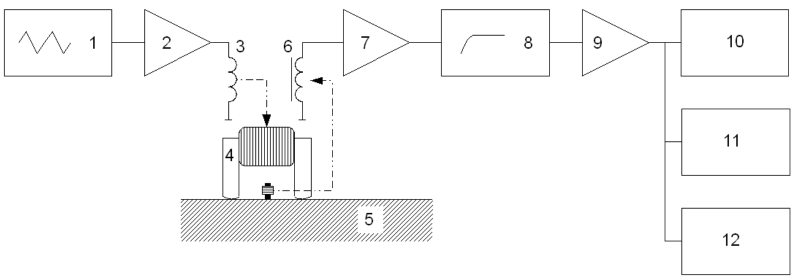

Fig. 3. Block diagram of measuring apparatus: 1 – sawtooth generator, 2 – power amplifier, 3 – magnetization winding, 4 – yoke, 5 – tested material, 6 – detection coil, 7 – preamplifier, 8 – high band filter, 9 – amplifier, 10 – RMC converter, 11 – envelope detector, 12 – Barkhausen pulse former

The task of magnetization unit made of saw-tooth voltage generator (1) and power amplifier (2) is to generate current supply magnetizing winding (3) on the yoke (4) of measuring head.

This head is an integral part of measuring equipment fulfilling the dual role - to produce an alternating magnetic field in the test element (5) and the detection of Barkhausen jumps. In its classic form, between the yoke poles detection coil is wounded on ferrite core (6). Moreover, to eliminate interference, the head is usually placed inside the shielding cover.

Detected Barkhausen signal is noisy and has very low amplitude. From this reason must be conditioning. In first stage is amplified with gain near 80 dB by instrumentation amplifier (7). Next, the high pass filter (8) eliminates the harmonics of magnetization current and network 50Hz. At the end, clean MBN signal is finally amplified to usable level by second amplifier (9).

Then the amplified MBN signal is fed to the processing block, where are determined its basic parameters: True RMS voltage (10), voltage signal of envelope and amplitude (11) and the Barkhausen noise pulse series in TTL standard, corresponding to Barkhausen jumps with an amplitude of voltage above a certain value.

In the presented in [12] measurement system, the determined Barkahusen parameters were acquired by PCI1711 or DAQ 3000 Board acquisition card and analyzed further on PC computer.

The described apparatus, due to a wide range of measurement parameters modification allows the study of a variety of ferromagnetic materials. It allows, inter alia, choosing one of six frequencies magnetization in the range 1 to 38 Hz, thus, the depth of measurement can be controlled to some extent. Maximum magnetizing current is at least 1A. Measurement channel is characterized by the maximum total gain of 120 dB that can be adjusted with steps of 5dB.

Mechanic positioning system of measuring head

Originally developed system of measuring head positioning was as mechatronic device, whose design was modeled on the solutions used in CNC milling machines [11]. It allowed free movement of the head in three-dimensional XYZ Cartesian coordinate system with dimensions of 700x350x50 mm.

The ground of the construction is the base frame, along which moves the transverse horizontal carriage. Along it, the vertical support carriage, used to lifting and lowering the measuring head, is moving. The base frame of positioning system as well horizontal carriage were built from aluminum closed-section 60 × 25mm. In addition, to the unit frame, a scale for easy determination of the position coordinates of the test element relative to the zero reference point was glued.

The movement of supports was realized by using toothed belt, driven by multi-gear with step motors. In relation to the previous version of the positioning device, presented in [1] several significant changes were introduced. First off all, the vertical shift of measuring head that was implemented with the helical gear, driven directly by additional step motor, by new unit with pneumatic actuator was replacement. This solution lets to do the tests more fast and is less sensitive to failure. Also in new concept of control of all system by PLC, this is easier for implementation.

A detailed view of new concept of measuring head lifting was shown in Fig. 4. This unit shares the same mounting plate base as in solutions with step motor, to avoid significant changes in basic construction. To this plate, micro pneumatic actuator was screwed. The MXH6-10 cylinder type, with precision guide rail using linear bearings, was used. Between the mounting bracket and the shield of head a two-ply shock absorber was placed. Additional shock absorber material, inside the cover was used, to amortise the measuring head during the lowering. The method of fixing the measuring head allows the longitudinal and small transversal tilting angle. Thanks to this, matching to the surface of the tested material was ensured.

For the lower position detection of measuring head, on the cylinder tube the position sensor switched by piston was clamped.

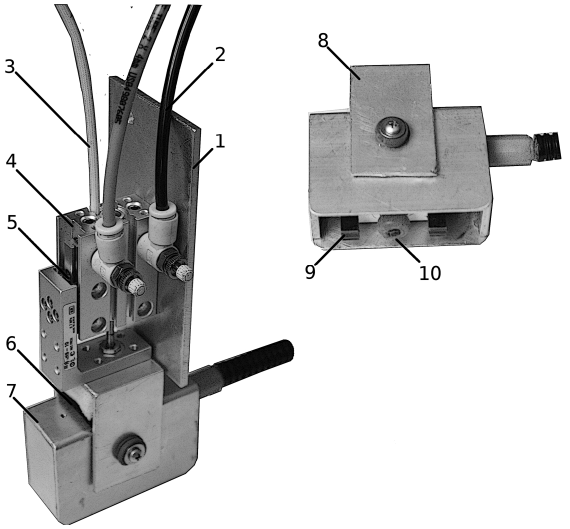

Fig. 4. Details of measuring head lift system: 1 – mount plate, 2 – compressed air pipe, 3 – position sensor wiring, 4 – cylinder, 5 – guide rail, 6 – shock-absorber, 7 – shield of measuring head, 8 – mounting bracket, 9 – pole of the yoke, 10 – detection coil

Control system

The solution involving the use of computer unit PC as the controller of the positioning system although very effectively in laboratory environment possessed a few limitations. Primarily, the step motors drivers were controlled and all phases were generated from the parallel port of PC. Nowadays in some standard computer there is a lack of this interface, so can limit further usable of this solution.

Also there wasn't feedback giving information about real position of measuring head. The coordinates were only calculated from the start point. In case of control problems, step lacks, the real position could be different from the calculated. Moreover, own author's computer program doesn't allow for remote control of its work. This all could limit industrial usable of this system in the future.

In a new concept of control system, the PC computer is replacement by PLC controller. The block diagram of this system is presented in Fig. 5. The main part is Vision V260 PLC unit (1). This controller is equipped with an operator panel contains graphical display and buttons. Still under developed controller program allows works in two modes. The first is manual control of the position of the head and measurement initiation by the panel. The second mode, semi-automatic allows the executions series of measurements but needs from the operator a few initial calculations and reactions during operation.

The direct control of stepper motors for XY movement was realized by simple independent drivers (3, 4). It needs only two two-state signals: START/STOP and LEFT/RIGHT given from PLC. These drivers consist inside its structure: pulse generator, phase decoder and power output.

Motors via the multi-gear transmission with toothed belts move the carriages (5, 6). The role of the feedback media about their location meets the electrical impulses which are counted by the PLC. Their number per unit time is proportional to the rotational speed of last gear driving towing belt.

If the desirable XY position is achieved, the controller triggers the lowering of measuring head by the cylinder. For the air flow control, the solenoid valve FV52M5 type was used. Due to minimize shock impact, the air pressure form the compressor had to be reduced. For this operation, the air line combo with filter, regulator and lubricator OU-1/4 Mini type was used (2).

After right lowering, indicating by the magnetic sensor, the PLC initiates the appropriate measurement of Barkhausen signal by the apparatus (8). In the present state, the MBN parameters are still acquiring by data acquisition card enabled by PLC, but the works has been now concentrated on implementation DDE Server and data exchange systems.

After measurement the head is lifting up and moving to the next position. The control mechanism doesn't allow to it if the head is not in the upper position.

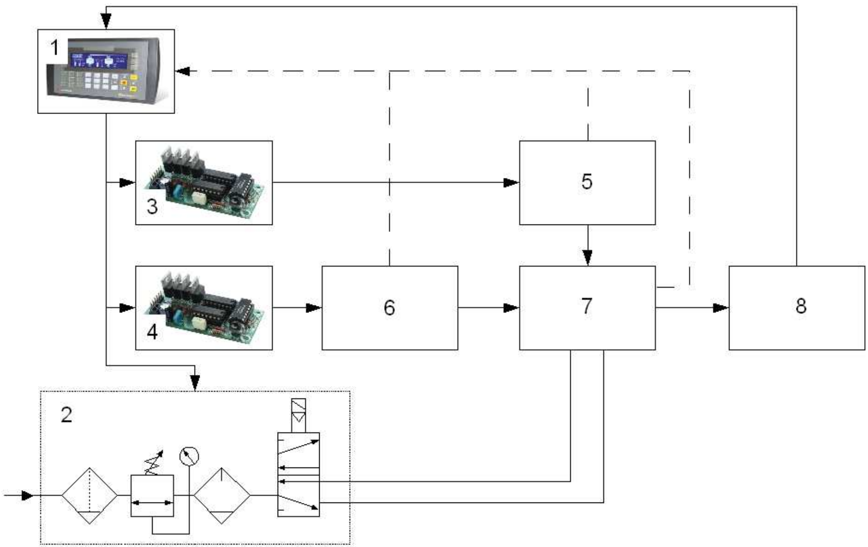

Fig. 5. Block diagram of positioning control system: 1 – programmable logic controller, 2 – pneumatic system, 3&4 – step motor drivers, 5 – mechanism of *Y* axis positioning system, 6 – mechanism of *X* axis positioning system, 7 – lift system and measuring head, 8 – measuring apparatus. The dashed line indicates the flow of feedback signals

Summary

Described in this paper the system for automation of the process of technical diagnostics using Barkhausen phenomenon, is the original technical solution in this field. Obtained preliminary results of investigations allow concluding that it can be used to diagnose the state of stress and microstructure in many industries such as metallurgy or machine building.

By eliminating the direct human impact on the process of measuring the Barkhausen noise parameters, a significant improvement in the arbitrariness of the results of measurements was achieved, mainly related to increased repeatability conditions of touchdowns the measuring head during testing.

Also have been achieved much more precise positioning of individual points and significantly reduced the effort in the performance of diagnostic tests.

The solution, using PLC device for control will allow integrating this system with existing industrial system of data processing and is more universal than solution based on personal computer.

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