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System for Complex Non-Destructive Testing of Mechanical Engineering Materials

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Abstract
New modular devices for non-destructive control of the composition and physico-mechanical characteristics of engineering materials used in laboratory and production conditions are presented. These devices can be used independently or as part of an automated system for complex non-destructive testing. Transducers are presented for precise measurement of ultrasound parameters, magneto-noise and magneto-acoustic characteristics of Barkhausen magnetic noise in non-destructive determination of physico-mechanical properties of materials. The research was done to test the applicability of the presented devices for complex non-destructive testing of the mechanical properties of structural steel samples and gray iron castings.

Keywords: complex non-destructive testing, non-destructive information parameters

Introduction

Modern industry requires research, development and implementation of devices and automated systems for non-destructive quality control and diagnostics of the physical-mechanical properties and structure of materials and equipment used in practice. The complex research and assessment of the properties of materials and products, carried out through the simultaneous use of several non-destructive methods, combines and complements each other's capabilities for rapid evaluation of the physico-mechanical characteristics and structure of controllable materials [4,6,7,8,9].

2. Purpose of work

The aim of the present work is to test a system for complex non-destructive testing of materials. Two new devices are presented – a modular device for complex magnetonoise and magneto-acoustic control "MULTITEST-MC 10" and a modular device "MULTITEST-CD 10" for complex measurement of speed and attenuation of ultrasound in the controlled material. They can work as stand-alone devices for non-destructive control of engineering materials, as well as engage in synchronous operation for multi-parameter control [8,9]. Tested devices are also presented – testing pliers DK1OO.

3. Means, methods and materials for research

The automated system "MULTITEST" consists of 2 parts – Personal computer for automated processing, visualization and evaluation of data from the control, as well as management of the characteristics; Modular devices and devices (testing tongs, robots, manipulators) for measuring the non-destructive information parameters and for gripping, moving and classifying the measured samples, products and materials. The modular devices have an autonomous power

supply and can work independently or in a single automated system depending on the tasks set [2,3]. For the development of the "MULTITEST-MC 10" module methods based on the Barkhausen effect, Magnetic noise method, and the magnetoacoustic emission method were used [10]. The measured information parameters are the magnetic noise voltage E_{NB}, the magnetoacoustic pressure E_{MAE} and their dependences on the frequency f_B of the magnetic noise and on the magnetizing current I_B. The principal diagram and the method of operation of the device "MULTITEST – MS 10" are presented in more detail in [6,7,8]. For the "MULTITEST – CD 10" module, methods based on the attenuation effect and change in the speed *Cl* of propagation of bulk ultrasonic waves in solid materials were used with method of operation described in [3]. The appearance of the modular devices is presented in Fig.1. Two non-consumer programs have been developed for work in an automated system for the devices described above:

- Program mc04.m. It is intended for research work with MatLab. The device is connected via a serial port, and the data is saved in binary format in mat-files. It is started from the MatLab command line. at which the main panel appears with function buttons, through which the necessary actions are performed. If necessary, additional dialog windows and menus appear, and both graphical windows and the command window are used to enter information.
- Program for working with LabVIEW graphics software. It has been developed to allow online visualization and evaluation of results. This expands the capabilities of the system to measure and evaluate not only individual data, but also ongoing processes online through a graphical GUI interface [5].

Fig.2 represents a schematic diagram of the testing pliers for complex non-destructive control with two informative parameters. The modification for complex measurement of the two informative parameters magnetic noise voltage and magneto-acoustic voltage is shown in Fig.2.a). In this configuration the appliance works as follows. When releasing the trigger 1, the spring 6 and the manipulator arm 2 press with constant force the tested material 4 to the magnetic noise transducer 5 and the piezo-transducer 3.

a b

Fig.1. View of the modular devices: a) "MULTITEST CD 010"; b) "MULTITEST MC 010"

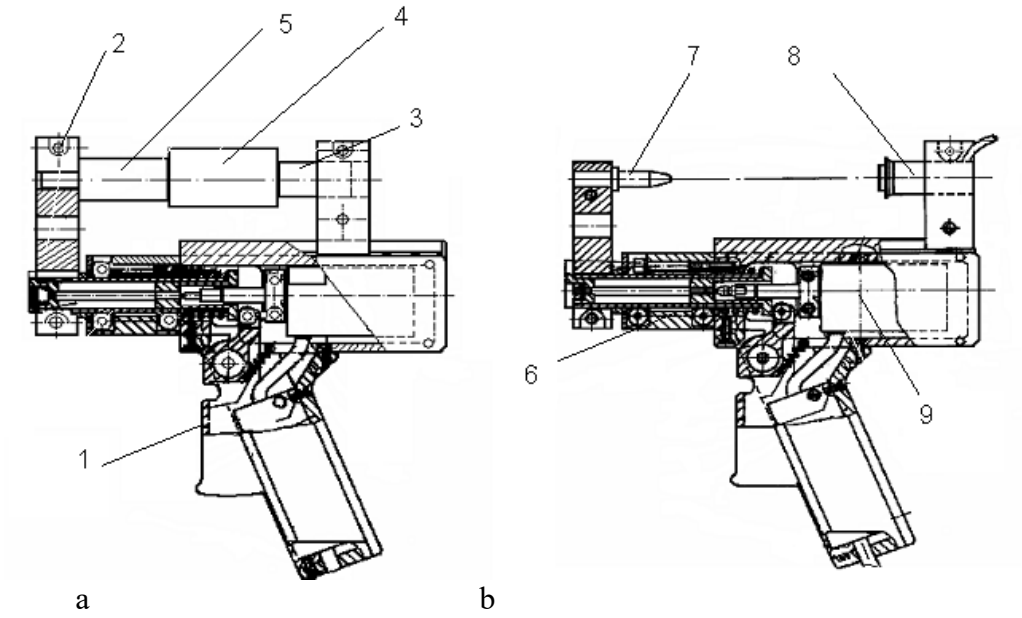


Fig.2. Appliance (testing pliers) for complex measurement of non-destructive informative parameters: a) magnetic noise voltage and magneto-acoustic voltage; b) velocity and damping of ultrasound.

Fig.2.b) is a schematic diagram of the other configuration – for measuring informative parameters speed and attenuation of the ultrasound. It operates with the modular devices for measurement of velocity and damping of ultrasound MULTITEST – CD 10 as follows. The material to be tested is placed between the tempered center 7 and the ultrasound detector 8. When releasing the trigger 1, the spring 6 and the manipulator arm 2 press with constant force the tested material to the optoelectronic transducer 9 and ultrasound detector 8. The relative thickness of the material d_y (measured with the ultrasound detector 8) is provided simultaneously with the real thickness d_0 (measured by the optoelectronic transducer 9) and the velocity and damping of the ultrasound are determined [3].

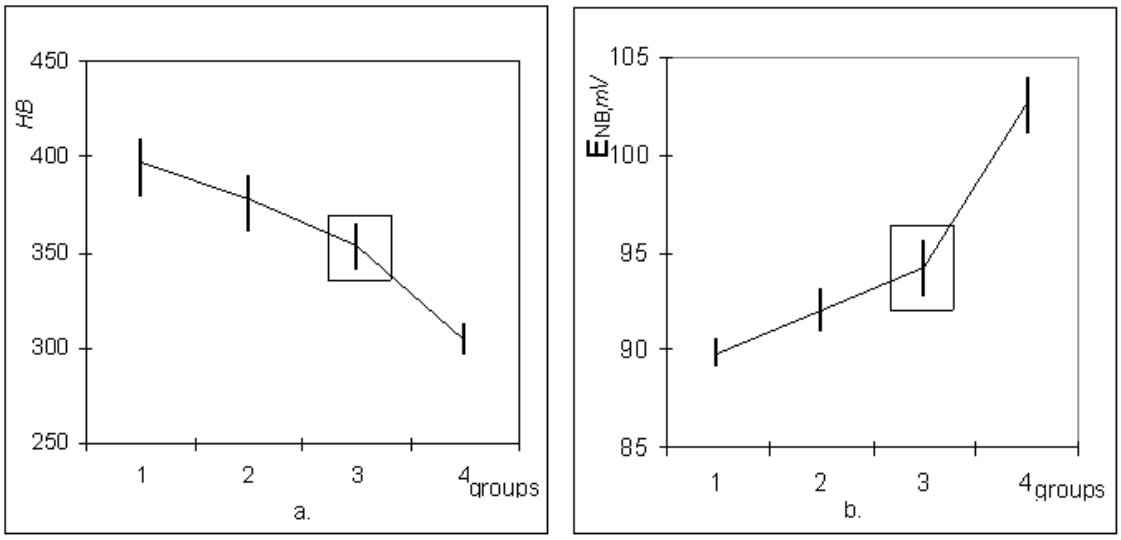
Table 1. Mechanical properties of reference samples of steel and cast iron.

Groups of samples from steel 40X, according to BSS		Groups of samples from grey cast iron (*СЧ)* and ductile iron (*ВЧ),* according to BSS		
№	Brinnel hardness *HB*	№	Tensility *Rm*, MPa	
1	380 – 410	1	120 – 157	СЧ15
2	360 – 390	2	300-337	СЧ30
3	330 – 365	3	450-500	ВЧ50
4	300 -310	4	590-630	ВЧ60
	-	5	640-675	ВЧ60-2

Table 1 presents the mechanical properties of the studied steel and cast iron samples.

4. Analysis of the experimental results

Fig.3.a) shows the results of the measurements of the hardness of the reference samples of steel 40X from Table 1. It shows the mean values of the span of the obtained values of *HB* for each group. Fig.3.b) presents the span of the values of the measured magnetic noise voltage E_{NB} in the same samples with a different level of heat treatment (Table 1, left column).
Fig.3 shows the choice of group 3 from Table 1 as good in terms of heat treatment. For this group, the span of the measurement values of the hardness HB and the magnetic noise voltage E_{NB} is marked with a surrounding square. The samples to the left are considered "hard" and to the right – "soft". The HB analysis of the steel 40X samples with equal heat treatment shows more samples classified in group 2 than should be and less samples classified in group 3 than should be. The E_{NB} analysis, on the other hand, shows less samples classified in group 2 than should be. Therefore, another non-destructive informative parameter is required for correct classification.



a b

Fig.3. Confidence intervals and mean values of the measurement of *HB* and the magnetic noise voltage in the groups of reference samples from steel 40X.

Fig.4 illustrates graphically the characteristic areas of the groups of reference samples of steel 40X, formed by means of complex measurement of the two informative parameters E_{NB} and E_{MAE}. The overlapping of the areas is a criterion for indistinguished areas of the groups of samples. As can be seen, if only the informative parameter E_{NB} is used, the characteristic areas 3 and 2 overlap, therefore they are undistinguishable, while the use of only the parameter E_{MAE} makes the areas 4 and 3 undistinguishable. When both informative parameters are used, the characteristic areas do not overlap, thus increasing the probability for correct classification of the tested material with respect to its structure or mechanical properties. After the characteristic areas are defined on the basis of the reference samples, details and materials with unknown parameters can be tested. In Fig.4 such measurements of materials with unknown properties are shown with a cross sign. Materials whose measurements lie outside the characteristic area 3, do not possess the necessary hardness. Similar is the methodology for comparative analysis of the results from the non-destructive testing of the groups of foundry cast iron samples (Table 1, right column), where the informative parameters are the velocity and damping of ultrasound in cast iron mouldings. The measurements and analyses are described in more detail in works [3,8].

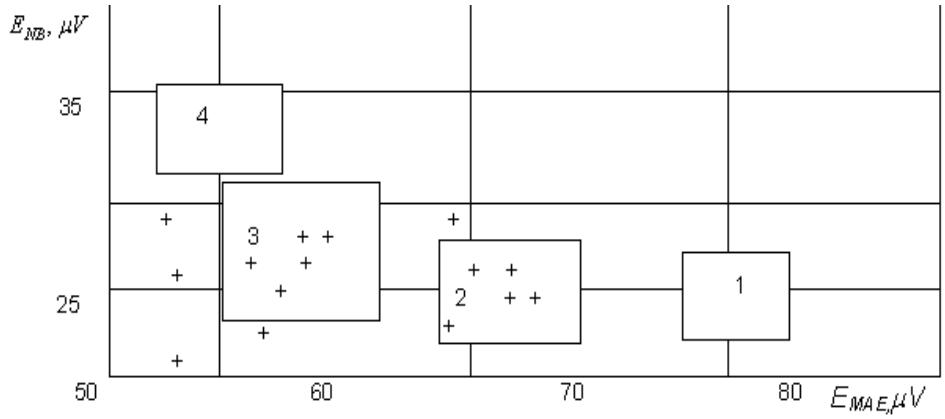


Fig.4. Characteristic areas of the steel 40X samples obtained after complex measurement of the two non-destructive informative parameters E_{NB} and E_{MAE}

5. Conclusions

The developed devices "MULTITEST-MC 10" (for complex measurement of the non-destructive informative parameters magnetic noise voltage E_{NB} and magneto-acoustic voltage E_{MAE}) and "MULTITEST-CD 10" (for fast measurement of the speed of volume ultrasound waves in solid materials) can be used for performing non-destructive testing of the structure and mechanical properties of metal materials and details, both in laboratory and industrial conditions. For this purpose, it is necessary to have preliminary measurements and correlations of the magneto-noise characteristics, speed and attenuation of the ultrasound through comparative samples with referenced structural-mechanical properties of the tested material.

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