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RESEARCH OF THE RESIDUAL MAGNETIZATION OF STEEL STRUCTURES AFTER LOCAL MAGNETIZATION WITH AN ATTACHABLE MAGNETIC TRANSDUCER

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ABSTRACT

The general problem of residual magnetization of steel products and a typical case of its formation after cyclic magnetization by an attachable type magnetic transducer in the process of magnetic structural analysis by hysteresis loop parameters determination is highlighted. The importance of reliable assessment of residual magnetization, including for quality control of demagnetization of steel products, is emphasized. The method of determining the residual magnetization and evaluating the quality of the demagnetization procedures of steel products by measuring the residual magnetic field is presented. Residual magnetization of 09G2C type steel specimen after hysteresis loop parameters measuring using a magnetic analyzer of the KRM-Ts-MA type, depending on the number of magnetization cycles and its distribution in the area of application of the attachable type magnetic transducer was investigated. It is shown that after multiple magnetization the level of residual induction in 09G2C type steel products does not exceed 0.75 mT, which allows welding without additional demagnetization operations. The tasks of further research on the influence of residual magnetization of steel products made of different steels on their further use and the formation of additional noise during eddy current testing are formulated. It was shown that the presence of residual magnetization after multiple measurements of hysteresis loop parameters does not affect the accuracy of their repeated measurement, which confirmed the stability of the measurement procedure with a KRM-Ts-MA type magnetic analyzer with respect to the residual magnetization created by it.

KEYWORDS: residual magnetization, magnetic structural analysis, attachable magnetic transducer, parameters of the magnetic hysteresis loop, demagnetization

INTRODUCTION. STATE OF THE PROBLEM

Magnetization, including to the technical saturation state, is often used during performance of magnetic and eddy current testing of structures from ferromagnetic materials. After termination of the external magnetic field, the material preserves a certain state of magnetization, which is characterized as residual magnetization. In engineering the term "residual magnetic induction" is sometimes used, although at closer consideration these characteristics differ by a magnetic constant. Residual magnetization depends both on the material magnetic properties and on the previous impact of the magnetic field on it. Moreover, residual magnetization of the products essentially depends on their shape, because of the action of the demagnetization factor, as well as on the impact of mechanical stresses and strains. Therefore, the respective changes in the residual magnetic field on the surface of the object of inspection from ferromagnetic steels are used for their diagnostics [1].

The inadmissibly high level of residual magnetization forms, in particular, after conducting magnetic particle inspection, which necessitates performance of additional demagnetization operations [2, 3]. The need for demagnetization is especially urgent for parts and elements of structures from alloyed steels, characterized by a high remanence level. For this reason, all the instructions on magnetic particle inspection envisage performance of mandatory demagnetization operations. Residual magnetization of a local zone of steel structures can also be the result of cyclic magnetization up to the state of technical saturation by attachable magnetic transducers (MT) during performance of magnetic structural analysis based on measurements of the parameters of magnetic hysteresis loop (MHL) [4–8]. This has not been given enough attention for a long time, and the level of residual magnetization after magnetic structuroscopy has not been studied.

The high level of residual magnetization has a negative effect on the welded structure quality, because of violation of optimal welding conditions. The welding arc instability and its deviations often are the cause of porosity and lacks-of-penetration, which may significantly limit the possibility of welding application in technological processes. It is known that the level of the magnetic field at the pipe edges after magnetic flaw detection reaches 25 mT. This level, however, can rise significantly (up to 120 mT) after abutment of the pipe edges for subsequent welding. Here, the level of the residual magnetic field in the welding gap, at which sound welding can be performed, cannot exceed 6–8 mT. However, it is better when the magnetic field at the pipe edges does not exceed 1.5 mT, which requires high quality and controlled demagnetization [9]. Moreover, residual magnetization influences the machining quality, because of chips sticking.

Depending on the part shape and dimensions, demagnetization can be performed by such most common methods:

- moving the part through the solenoid, to which alternating current is supplied, and removing it to a distance equal to five solenoid diameters (diagonals);
- reducing to zero the alternating current in the solenoid with the demagnetized part placed into it (solenoid length here should be greater than the part length);
- removing the part from the electric magnet, to which alternating current is supplied (or removing the electric magnet from the part);
- reducing to zero the alternating current in the electric magnet, in the interpolar zone of which the demagnetized part region is located.

Leading companies propose special devices for demagnetization of ferromagnetic products. In particular, a device for demagnetization of rods and pipes of EMAG M type (manufacturer is Institut Dr. Foerster GmbH, Germany) uses feed-through coils, powered by an alternating magnetic field of industrial frequency, which limits the possibility of demagnetization of products of the diameter and wall thickness of more than 30 and 5 mm, respectively [10]. A demagnetization device EMAG F, which ensures demagnetization of rods of more than 240 mm diameter and pipes with more than 25 mm wall thickness, has better characteristics. This device uses a solenoid with two demagnetization coils, where the frequency of the alternating magnetic field is regulated in the range of 5–100 Hz [10]. Known is a series of publications, dealing with development of improved methods of demagnetization of ferromagnetic assemblies and structures [9, 11–14]. Here, a low-informative method is often recommended to control the demagnetization quality, using small ferromagnetic parts [3]. More reliable are the procedures of demagnetization quality control, when the instruments for magnetic field measurement are used to conduct quantitative analysis of the residual magnetic field on the structure surface [9, 11].

The **objective** of the work is analyzing the influence of magnetization during performance of magnetic structural analysis by attachable MT on residual magnetization of the specimens and accuracy of magnetic parameter measurement.

EXPERIMENTAL PROCEDURE, SPECIMENS AND RESEARCH EQUIPMENT

Residual magnetization in the specimen local zone was created using a П-shaped magnetization system of the attachable MT from the set of magnetic analyzer KRM-Ts-MA (Figure 1, *a*), developed by SPF "Spetsialni naukovi rozrobky" (Kharkiv) [4–7]. Attachable MT with the generalized circuit of the magnetic analyzer is shown in Figure 1, *b*.

Experimental specimens of 460.0×60.0×4.00 mm size (Figure 1, *a*) were produced in the form of plates from low-carbon steel of 09G2S type (German analogs are 13MN6 or 9MnSi5), chemical composition of which corresponds to DSTU 8541:2015 (%): ≤0.12 C; 0.5–0.8 Si; 1.3–1.7 Mn; ≤0.3 Ni; ≤0.04 S; ≤0.035 P; ≤0.3 Cr; ≤0.12 N; ≤0.12 Cu. The studied steel is widely used, in particular, in production of pipes for oil and gas transportation.

Measurement of the vertical component of the residual magnetic field on the specimen surface was conducted, using a universal milliteslameter of MTU-1 type (SPF "Spetsialni naukovi rozrobky") with magnetically sensitive transducer based on Hall sensor (Figure 1, *c*), which ensures magnetic field measurement with 3 % error at measurement limit of 20 mT.

To create residual magnetization, magnetic analyzer MT was installed on the specimen surface. After that, 15 cycles of MHL parameter measurement were conducted. Evaluation of residual magnetization of the specimens was performed by measurement of residual magnetic field H_r on the specimen surface after 1, 3, 6, 8, 12 and 15 cycles of measurement in 5 zones of the specimen relative to poles of the П-shaped magnetization system of attachable MT (Figure 2, *a*), where: MT center and pole centers are designated by letters *A*, *B* and *C*, respectively, and side zones are designated by letters *E*, *D*. Measurement of the distribution of vertical component of residual magnetic field H_r on the specimen surface was conducted by the scheme as in Figure 2, *b*. Dotted lines in Figure 2 designate the places of MT pole mounting. After 15 cycles of MHL parameter measurement, specimen demagnetization was conducted by slowly moving it into the demagnetization coil and its subsequent removal. The demagnetization coil is made in the form of 560 turns of enamel wire of 0.95 mm diameter, with outer and inner diameter of 200 and 170 mm, respectively, and 46 mm height. Resistance of demagnetization coil at direct current is equal to 9 Ohms. Demagnetization

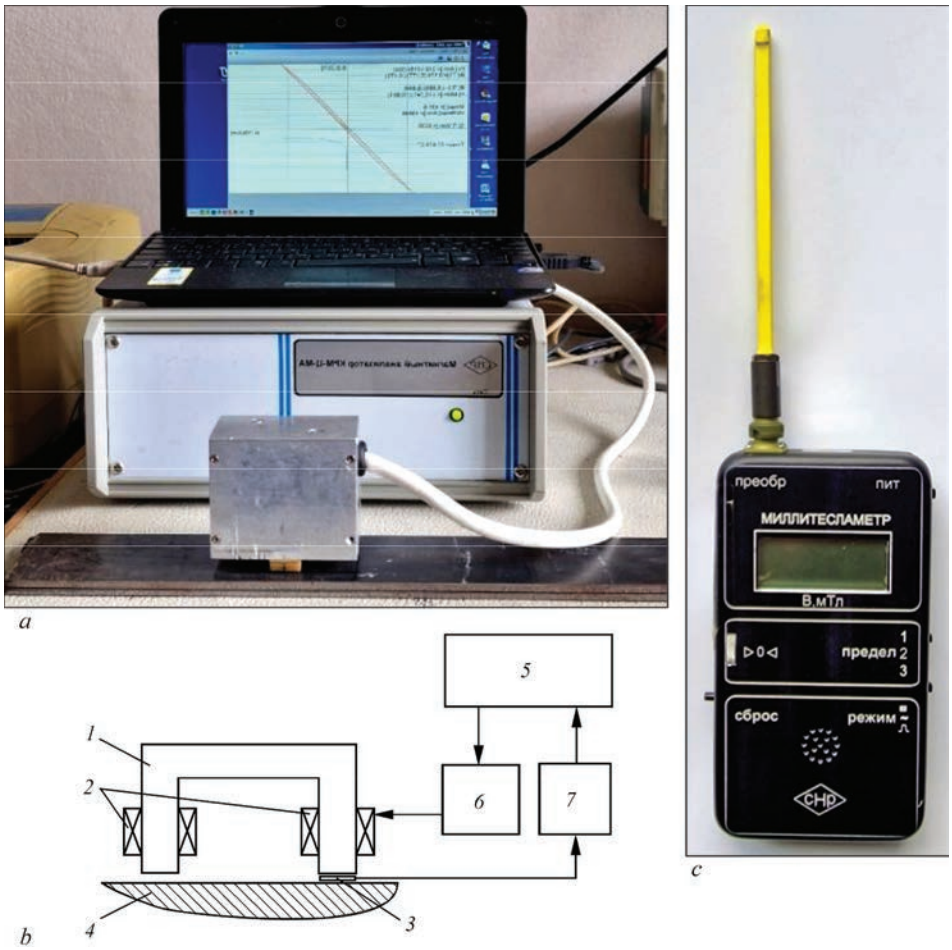

Figure 1. Magnetic analyzer of KRM-Ts-MA type with attachable MT on the studied specimen (*a*), design of attachable MT with the generalized diagram of magnetic analyzer (*b*), all-purpose milliteslameter of MTU-1 type (*c*); *1* — П-shaped core; *2* — magnetization reversal windings; *3* — Hall sensor for magnetic flux measurement in the magnetic circuit; *4* — object of control; *5* — circuit of control, measurement and indication; *6* — circuit of generation of currents of attachable MT winding; *7* — circuit of magnetic flux measurement

coil was connected to standard 220 V network, which created a demagnetization alternating electromagnetic field of 50 Hz 34.5 mT magnitude in its center.

Moreover, to determine the influence of residual magnetization on measurement accuracy, MHL parameter measurement was also performed after the measurement cycles without shifting the MT position on the specimen. Obtained values were compared with the values of the specimen coercive force in as-delivered condition and after demagnetization.

RESULT ANALYSIS

Dependence of residual magnetic field H_r on the specimen surface in zones *A* (×), *B* (●), *C* (○), *D* (▲) and *E* (▼) of MT application (Figure 2, *a*) on the number of measurement cycles *N* is given in Figure 3, *a*. One can see that residual magnetic field H_r on the specimen surface in the central and lateral zones of MP application is close to zero, which was anticipated, taking into account the zero value of the vertical component of primary magnetic field in these zones. The

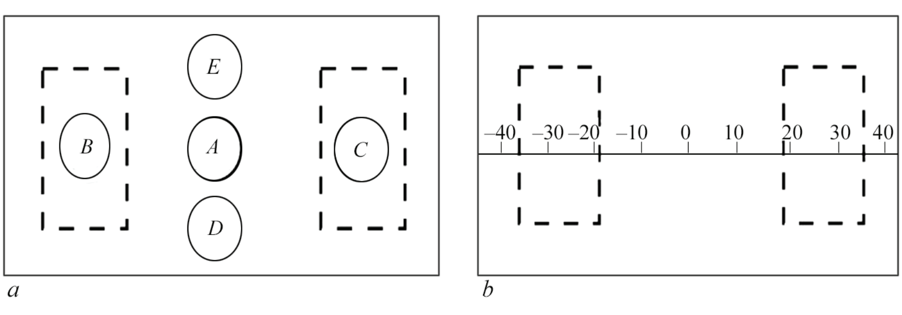

Figure 2. Zones of measurement of residual magnetic induction in MT action zone (*a*) and schemes of measurement of residual magnetic induction distribution

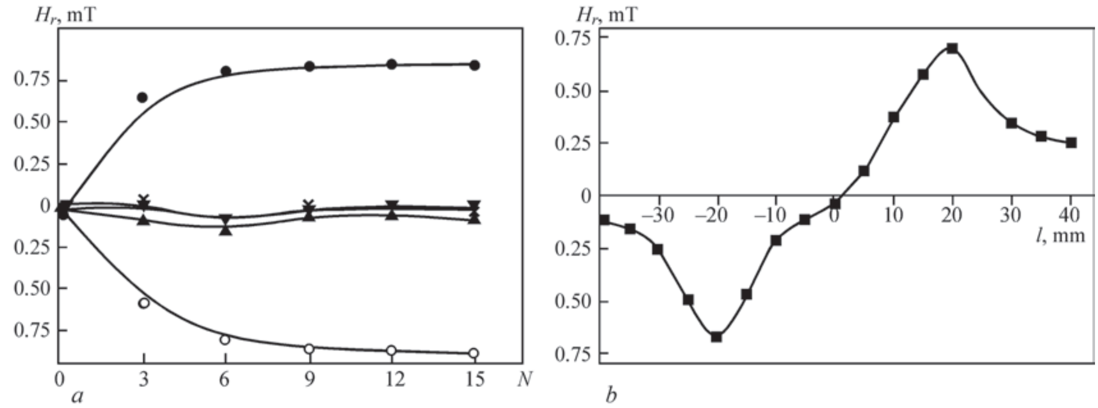

Figure 3. Changes of vertical component of residual magnetic field H_r in the zone of MT action, depending on the number of magnetization cycles in zones *A* (×), *B* (●), *C* (○), *D* (▲) and *E* (▼) (*a*) and its distribution in the zone of MT action after 3 measurement cycles (*b*)

values of the vertical component of residual magnetic induction H_r of the specimen in the centers of location of MT poles (zones *B* and *C*) are of different sign and they grow gradually with increase of the number of measurement cycles *N*. However, already after 6 measurement cycles residual magnetic field H_r on the specimen surface becomes close to the maximal value, and furtheron it practically does not change with increase of the number of measurement cycles ($N > 9$).

Distribution of the vertical component of residual magnetic field H_r after 3 measurement cycles (Figure 3, *b*) shows the presence of two maximums of different sign, which correspond to the centers of MT magnetic pole location. Here, even at multiple magnetization, the level of residual magnetic field H_r in specimens of steel of 09G2s type does not exceed 0.75 mT, which allows welding structures from this steel without conducting additional demagnetization operations, when the level of the residual magnetic field below 1.5 mT is believed to be optimal [9]. This, however, does not mean that such a conclusion can be made as regards other steels, particularly those, which are characterized by higher coercive force values. More over, it does not mean that even such a low level of residual magnetic field will not affect further performance of the steel products, for instance because of metal chips sticking, or it will not create significant noise, which often limits the possibility of application of eddy current flaw detection of ferromagnetic steels without stabilizing magnetization [15]. Thus, additional studies in these areas are also relevant.

Results of repeated measurements of MHL parameters of specimens with different residual magnetization showed that it did not affect the measurement accuracy which confirmed the stability of the procedure of measurements by magnetic analyzer of KRM-Ts-MA type. At the same time, it should be noted that the induced level of residual magnetization can have a more significant influence on the results of dynamic MHL parameter measurement by local MT, where significantly smaller values of primary magnetic field are used [16].

If it is necessary to reduce the residual magnetization after conducting magnetic structural analysis, we proposed complementing the cycle of MHL parameter measurement by an additional operation of demagnetization, using a series of pulses of different polarity alternating magnetic field, where the amplitude decays to a zero value (Uchanin V.M., Solomakha R.M. Method for determination of the magnetic and mechanical characteristics of ferromagnetic materials and monitoring the technical state of structures. Patent of Ukraine No. 154135. Publ. 11.10.2023, Bul. 41). To reduce the error of MHL parameter measurement, it is also proposed to apply alternating magnetic field pulses to the control zone, before conducting the measurement cycle of magnetization. Pulses of different polarity alternating magnetic field, the amplitude of which decays to zero, can be generated by windings of the electric magnet of П-shaped MT, used to realize the cycle of MHL parameter measurement.

CONCLUSIONS

1. The general problem of residual magnetization of steel products and the characteristic case of its formation after cyclic magnetization by an attachable MT during magnetic structural analysis by MHL parameters is highlighted. The importance of reliable evaluation of residual magnetization is emphasized, in particular for quality control of demagnetization of steel products. A procedure is presented for determination of residual magnetization and evaluation of the quality of the procedures of steel product demagnetization by measurement of the residual magnetic field.

2. Residual magnetization of specimens from steel of 09G2S type was studied after conducting measurements of MHL parameters, using a magnetic analyzer

of KRM-Ts-MA type, depending on the quantity of magnetization cycles and its distribution in the zone of application of an attachable MT. It is shown that at multiple magnetization the residual induction level in the products from steel of 09G2S type is not higher than 0.75 mT, that allows performance of welding without conducting the additional demagnetization operations.

3. The tasks of further studies on the influence of residual magnetization of steel products from different steels on their further application and generation of additional noise during performance of eddy current testing are formulated.

4. It is shown that presence of residual magnetization after multiple measurements of MHL parameters does not influence the accuracy of their repeated measurement, which confirmed the stability of the procedure of measurement by magnetic analyzer of KRM-Ts-MA type as to residual magnetization generated by it.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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