Multiparameter method of surface hardening quality testing

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Abstract. Measurements of the magnetic characteristics (coercive force, residual induction, induction of saturation) of objects that had different thicknesses of the hardened layer were made. The influence of an unstressed core on the measurement results, as well as the depth of the strengthened layer on the shape of the hysteresis loop, is investigated. The conclusion is made that it is possible to estimate the properties of a hardened layer by means of a single measurement with the help of the hardware-software system DIUS-1.15M

1 Introduction

Such type of the processing of products (automotive valves, rolls, etc.) as surface hardening of steel products is carried out to improve their wear resistance and fatigue failure resistance.

The main types of surface hardening include the surface hardening of steel using the various methods of heating the product (flame, electrolytes, molten metals and salts, laser, high and industrial frequency currents); chemical-thermal treatment of steel (cementation, nitration, cyanidation), hardening by the method of surface-plastic deformation [1]. Surface hardening increases the electrical resistance and greatly changes the magnetic properties of the hardened layer. Thus, when quenching by HD, the coercive force of the quenched layer is 2-4 times greater than the coercive force of the core of the articles. This is because the core structure - ferrite + perlite - is "soft" in the magnetic ratio (Hc = 15-20 A / cm). The high value of the quenched layer is explained by the same reasons as in the case of bulk hardening of steel [2].

The most widely used non-destructive methods for controlling surface hardening are acoustic, eddy current, and also magnetic methods. Magnetic control methods can be widely used to assess the quality of products that are surface hardened in various ways. Taking into account the features of the reversal magnetization of two-layer ferromagnetics, as well as differences in the stability of the magnetic states of the hardened and non-hardened layers, it is possible to significantly expand the functional capabilities of the magnetic control methods and create instruments for separately determining the physico-mechanical characteristics of each of the layers and their thicknesses.

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The most common magnetic method of quality control of surface hardening is still the coercimetric method [3, 4]. However, for a separate determination of the depth and hardness of a hardened layer, it is necessary to measure twice the average value of the coercive force of the controlled section of the product with the help of two additional transducers of different sizes. This aspect increases the complexity of control significantly. Therefore, it is desirable to carry out the control with a single transducer with the determination of two magnetic parameters that would give independent information on the depth and hardness of the layer.

The tasks of this investigation were:

- determination of optimal parameters for measuring the depth of a hardened layer for local magnetization of a two-layer ferromagnetic object;
- determination of the influence of the hardened layer on the shape of the magnetic hysteresis loop.

2 Description of samples and measurement method

In the presented study, the measurements were carried out using three groups of samples.

The first group of samples consisted of plates of various thicknesses from 62C2 hardened steel, which had a width of 40.5 mm, a length of 90.5 mm and a variable thickness within 1.95-4.96 mm.

The second group of samples consisted of the plates of the same size with different magnetic properties, simulating an unhardened core. Geometric dimensions of this group of samples: 7×39.2×89.5 mm.

The first and second groups of samples simulated a hardened layer during the procedure of testing. As a non-hardened core, a ground plate with dimensions of 100×170×34 mm, made of annealed steel 3, and a steel specimen with dimensions of 97.1×34.2×23.2 mm.

To measure the magnetic characteristics, we used the hardware-software system (HSS) DIUS-1.15M [5], a general view of which is shown in Fig. 1, intended for multi-parameter structuroscopy of ferromagnetic products. The device allows to locally determine the magnetic properties of the material of the controlled objects. DIUS-1.15M can be used for non-destructive testing of ferromagnetic products in the presence of a correlation relationship between the controlled parameters and the magnetic properties measured by the device. Figure 2 shows a schematic representation of an attached measuring transducer placed on a controlled article (d). The transducer consists of a solid U-shaped magnetic circuit (a) with two magnetizing windings (c), a converter-hole (b) and Hall-sensors(e).

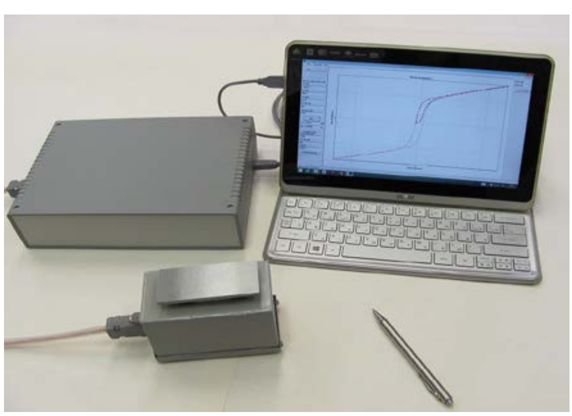

Fig. 1. General view of HSS DIUS-1.15M

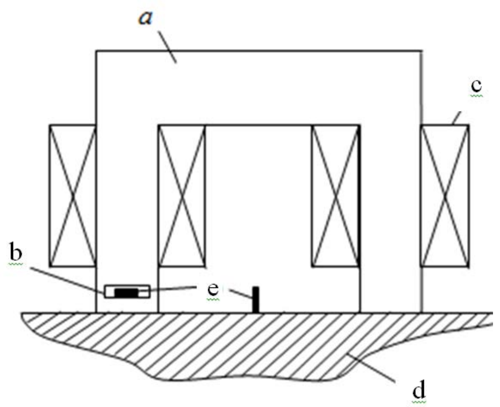

Fig. 2. Schematic representation of an electromagnet with a converter- hole

3 Experimental

3.1 Influence of magnetic properties of the core on measurement results

A change in the thickness of the quenched layer on three samples with different magnetic properties imitating an unstressed core has been simulated with the help of 62C2 hardened steel samples. The magnetic properties of a compound sample were measured using the HSS DIUS-1.15M for different thicknesses of the hardened layer.

Figure 3 shows the dependencies of the magnetic characteristics measured with DIUS-1.15M, such as coercive force, residual magnetic induction, magnetic saturation induction from the depth of the simulated reinforced layer for two cores.

As can be seen from Fig. 3a, the coercive force of both the first and second samples increases monotonically to a layer thickness of 8 mm.

Figures 3.2 and 3.3 show the dependences of the residual magnetic induction and induction of saturation on the depth of the hardened layer. Dependencies change monotonically.

3.2 Effect of the depth of the hardened layer on the shape of a locally measured hysteresis loop

The thickness variation of the hardened layer on a ground plate with dimensions of 100x170x34 mm made from annealed steel 3 has been modeled with the help of grinded plates of various thicknesses made from hardened 62C2 steel. The DIUS-1.15M measured the relative values of strengths of the magnetic field on the surface of a two-layered object, after its reversal magnetization along the descending branch of the hysteresis loop, from the thickness of the hardened layer at different values of the magnetic flux. The experimental results are shown in Figure 4.

When carrying out the measurements, two sensors were used: the sensor 1 with the dimensions of the electromagnet pole 20x40 mm, the sensor 2 - 12x28 mm.

Figure 4 shows the dependences of the relative magnitude of the magnetic field strength on the surface of a two-layer object, after its reversal magnetization along the descending branch of the hysteresis loop, from the thickness of the hardened layer at different magnetic flux values for two sensors.

The relative values of the magnetic field strength increase monotonically with increasing depth of the hardened layer D from 0 to 14 mm at relative flux values Φ = 100 mV, and at Φ = -500 mV, the relative values of the voltage reach saturation in case of measurements with help of the first sensor.

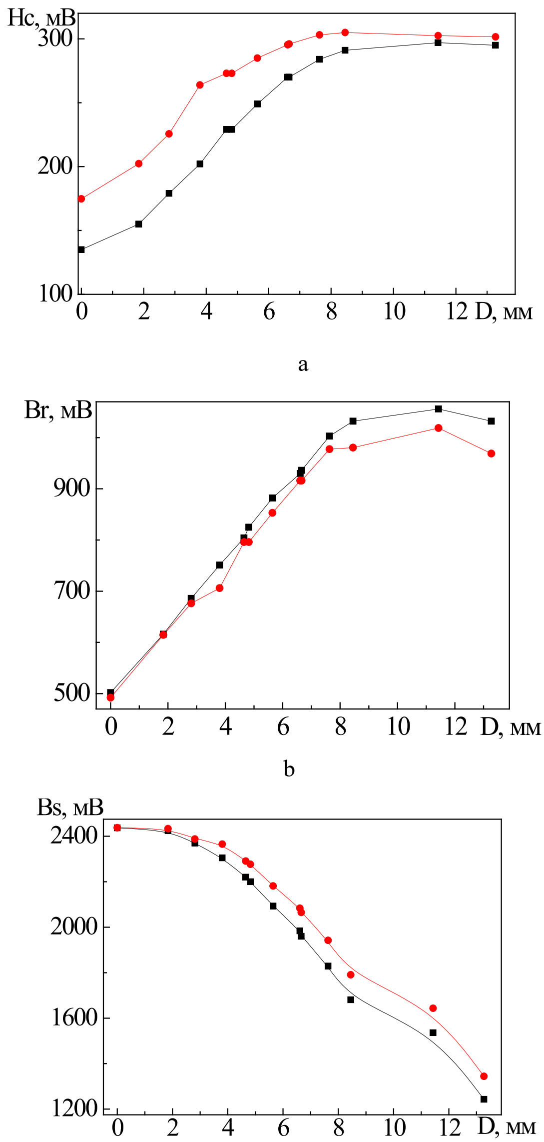

Fig. 3. Dependences of magnetic characteristics on the depth of the hardened layer (a - coercive force, b - residual magnetic induction, c - magnetic induction of saturation)

And the relative values of the magnetic field intensity increase practically linearly with increasing depth of the hardened layer D from 0 to 14 mm with a relative flux value of Φ = 100 mV. At Φ = -500 mV, the field strength increases monotonically until saturation in case of measurements with help of the second sensor.

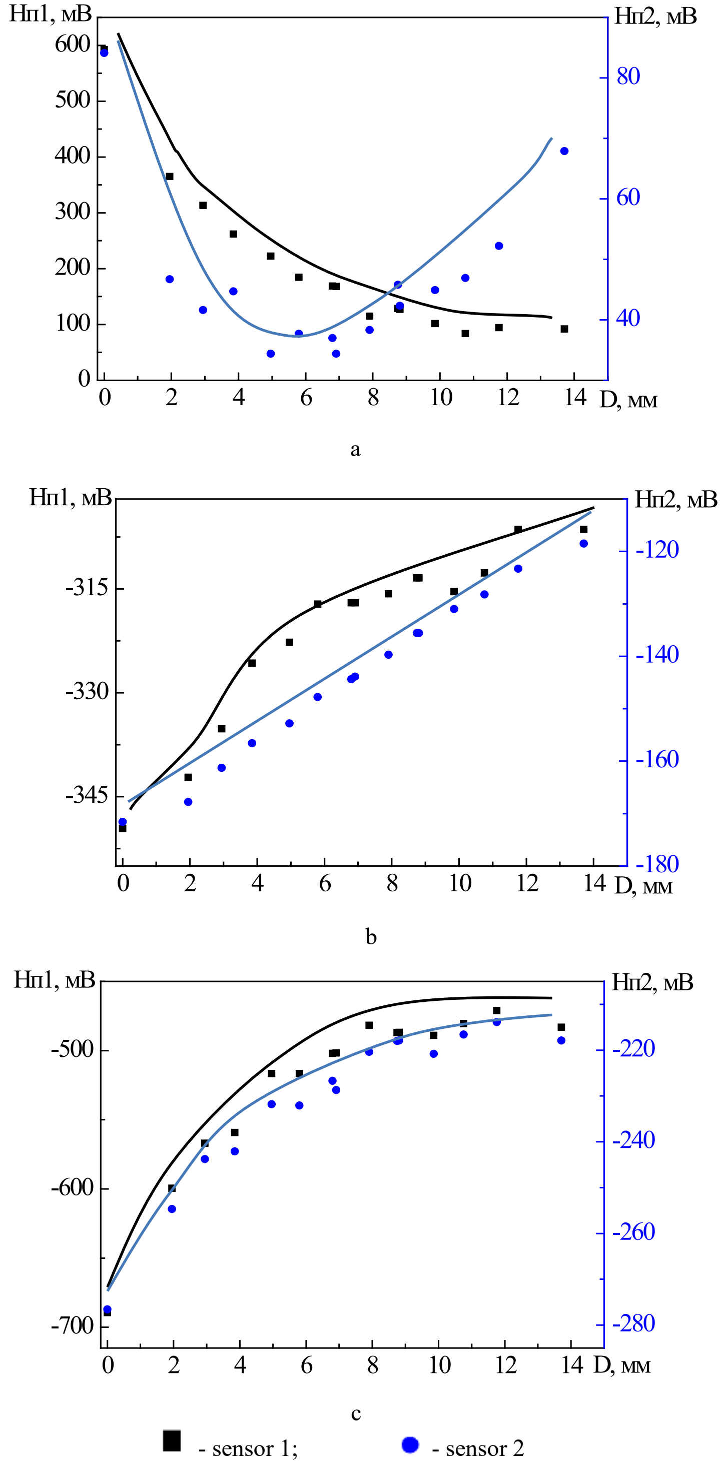

Fig. 4. Dependences of the relative magnitude of the magnetic field strength on the surface of a two-layer object, after its magnetization reversal along the descending branch of the hysteresis loop, from the thickness of the hardened layer at different magnetic flux values for two sensors (a – Φ = 850 mV, b – Φ = 100 mV, c – Φ = -500 mV)

4 Conclusion

During carrying out the study, it has been established that the depth of the strengthened layer can be determined from the magnitude of the magnetic field corresponding to a given value of the induction (magnetic flux) on the descending branch of the magnetic hysteresis loop. In this case, unlike the known coercimetric method, the range of controlled thickness may exceed the thickness of the poles of the electromagnet. It was also found that the presence of a hardened layer influences the shape of the magnetic hysteresis loop. It is possible to control the depth of the hardened layer by measuring the relative magnitude of the magnetic field strength on the surface of a two-layer object, after it is reversed in the descending branch of the hysteresis loop at a fixed value of the magnetic flux.

The proposed control techniques can be practically realized with the help of the mobile hardware-software system DIUS-1.15M when measuring the above parameters of monitoring by one sensor.

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References

1. V.N. Kostin, *Electromagnetic Control: educational publication* (Ural Federal University, IPM UB RAS, Ekaterinburg, 2016)
2. M.N. Mikheev, E.S. Gorkunov, *Magnetic methods of structural analysis and non-destructive testing* (Science, Moscow, 1993)
3. V.E. Shcherbinin, E.S. Gorkunov, *Magnetic control of the quality of metals* (Ural Branch of the Russian Academy of Sciences, Yekaterinburg, 1996)
4. Kostin, V.N. *On some new possibilities for local measurement of the coercive force of ferromagnetic objects*, Defectoscopy, v.**7**, pp. 3-14 (2012)
5. V. N. Kostin, Ya. G. Smorodinskii, *Multipurpose software-hardware systems for active electromagnetic testing as a trend*, Russian journal of nondestructive testing, v.**53**, pp. 493-505 (2017)
6. V.N.Kostin, *Electromagnitniy control : uchebnoe izdanie* (UrFU, IMP UB RAS, Ekaterinburg, 2016)
7. M.N. Mikheev, E.S. Gorkunov, *Magnitniye metody strukturnogo analiza i nerazrushayushchego kontrolya* (Nauka, Moscow, 1993)
8. M.N. Mikheev, E.S. Gorkunov, *Magnitniy control kachestva metallov* (IMP UB RAS, Ekaterinburg, 1996)
9. V.N. Kostin, O.N. Vasilenko, *On new possibilities for making local measurements of the coercive force of ferromagnetic objects*, Russian Journal of Nondestructive Testing, v.**7(48)**, pp. 401-410 (2012)
10. V. N. Kostin, Y. G. Smorodinskii, *Multipurpose software-hardware systems for active electromagnetic testing as a trend*, Russian journal of nondestructive testing, v.**7(53)**, pp. 493-505 (2017)