THICKNESS MEASURING OF NICKEL COATINGS ON STEELS WITH VARIOUS MAGNETIC PROPERTIES

A. A. Lukhvich, O. V. Bulatov, A. L. Lukyanov, and A. A. Polonevich
Institute of Applied Physics of the National Academy of Sciences of Belarus, Minsk, Belarus,
E-mail: lab1@iaph.bas-net.by

During realization of the nondestructive testing of thickness of nickel coatings, the main interfering factor is the strong dependence of physical properties of the coatings on the structural state of nickel. If nickel is coated on a nonmagnetic base, at the expense of use of the magneto-dynamic method [1-5], accuracy of the testing is considerably growing, resolution is increasing, and measurement range is widening. According to the results received earlier [5], the magneto-dynamic transducer with optimized parameters provides testing of nickel thickness up to 1000 μm and more with the error ~5 %, and the resolution at the beginning of the range is several tenth parts of micrometer.

The situation becomes considerably complicated when the base has magnetic properties. In this case because of an informative signal is caused by magnetization not only of the nickel coating, but also the base, the signal contains the non-informative component, value of which considerably depends on properties of the base and the cover. Hence, while passing from the nonmagnetic base to magnetic, inevitably, the resolution is decreasing and the measurement range is shortening. By virtue of it, the range that is provided by modern magnetic thickness gauges while testing of nickel coatings on low-carbon steels does not exceed 150 μm. The investigations for substantiation of a possibility of testing of nickel coatings on steels with different magnetic properties in a number of cases that important for practice have not been carried out until now.

In this paper, the results of researches of possibilities of the magneto-dynamic method that is used for testing of nickel coatings on steels with properties, which vary from practically nonmagnetic to strong-magnetic are presented. In particular, the data of character of magnetization distribution in the coating and base at different value of the primary magnetizing field are given, as well as the data of dependence of the resolution and measurement range on size of this field are offered.

For producing a number of details that are coated by layers of galvanic nickel, steel grades 12Х18Н10Т, 12Х21Н5Т, 06Х15Н6МВФБ, and 03Х12Н10МТР-ВД are used. Because the information about magnetic properties of these materials in literary sources has not been found, their normal magnetization curves were got experimentally. For this purpose from named steels and from steel 3 in a condition of delivery, pairs of identical discs were made. From a disc of each pair the ring was cut out; for all rings, external diameter was more internal approximately in 1,2 times. On each ring 400 turns of a measuring winding by a diameter of 0,1 mm, then 300 turns of a magnetizing winding by a diameter of 0,5 mm were uniformly applied. By this procedure, five ring specimens were made. Alexander Osipov in Vladimir Matiuk's laboratory on the certified apparatus УИМХ-1 [6] carried out investigations of their magnetic properties. The normal magnetization curves of all specimens are presented in fig. 1; there for comparison the curve of pure nickel is shown.

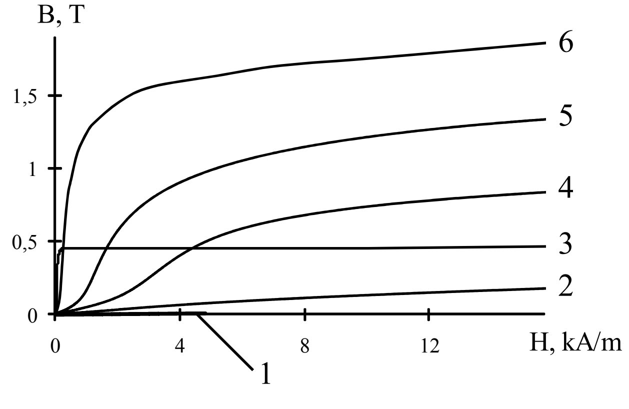

Fig. 1. The normal magnetization curves of materials of the coating and base: curve 1 (it practically interflows with the axis H) – steel 12Х18Н10Т, 2 – steel 12Х21Н5Т, 3 – pure nickel, 4 – steel 06Х15Н6МВФБ, 5 – steel 03Х12Н10МТР-ВД, and 6 – steel 3

Judging by character of the curves in fig. 1, the properties of the steels under consideration vary in the extremely wide range – from practically nonmagnetic (steel 12X18H10T) to strong-magnetic (steel 03X12H10MTP-ВД), and the properties of steels 12X18H10T and 12X21H5T are weaker than nickel properties, but the properties of other steels are stronger. Hence, in practice while testing of thickness of nickel coatings on such bases is carrying out, one should expect very big variation of the resolution and measurement range.

The curves shown in fig. 1 were used for the computations made by means of the finite element method. All simulated magneto-dynamic transducers had the common construction arrangement but differed in magnet energy (the product of specific energy of material of a magnet on its volume). In a role of products under test, models of the discs having an equal diameter were used; each disc consisted of the base, material of which was one of five mentioned steels, and the nickel coating by thickness up to 2500 μm.

The distribution of magnetization of the coating and base with different value of the primary magnetizing field was researched. The module of this magnetization was computed in the coating along its all thickness and in the base on the depth 500 μm. In fig. 2 the distribution of the magnetization module for the transducers with magnet energy about 15 and 180 mJ when base thickness is 1000 μm and nickel thickness is 400 μm is presented.

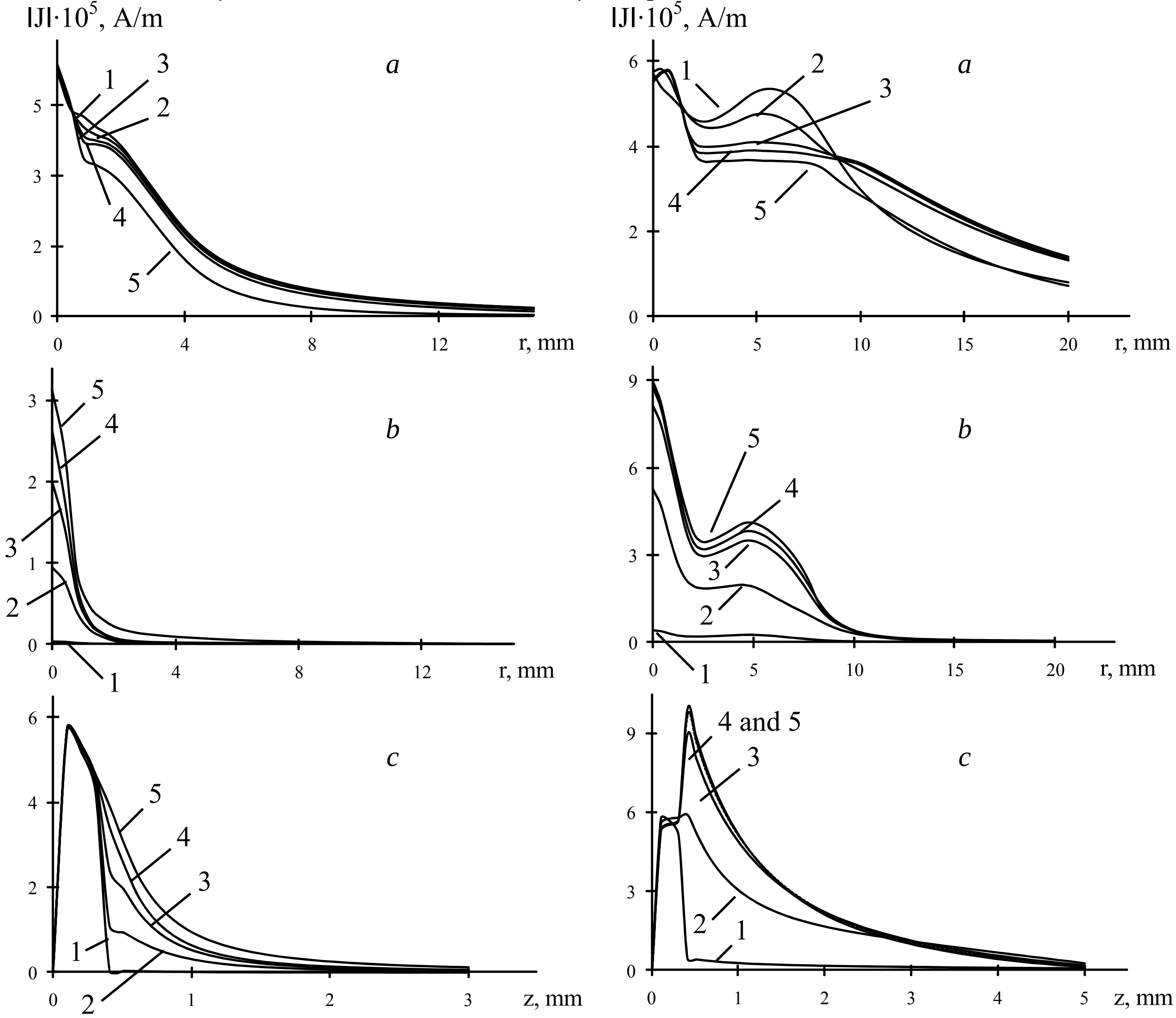

Fig. 2. The distribution of the module |J| of magnetization along the radius r and depth z with different magnet energy: *a* – in the coating, *b* – in the base on depth 500 μm, and *c* – along an axis of symmetry of the disc model; the plots at the left – magnet energy is about 15 mJ, on the right – about 180 mJ; curve 1 – steel 12X18H10T, 2 – steel 12X21H5T, 3 – steel 06X15H6MBФБ, 4 – steel 03X12H10MTP-ВД, and 5 – steel 3

The charts show that strengthening of the magnetizing field always results in increasing of magnetization of the base and coating. At a weak magnetizing field, considerable strengthening of magnetic properties of the base results in inessential growth of its magnetization, while at a strong field, magnetization of the base can appear more than coating magnetization. It is caused by that even at enough big magnet energy, magnetization of the coating in the area that is directly under the pole tip of the transducer cannot exceed the saturation magnetization of nickel (it is about 0,6·MA/m), while magnetization of the base that is steel 3 can reach 1 MA/m. It is clear that further strengthening of properties of the base results in its even more magnetization. Because the non-informative component contained in the transducer signal and caused by the secondary field of the magnetized base is mainly formed by the base properties, a transducer with any magnet energy on steel 3 provides the measurement range that is much narrower than the range on steel 12X18H10T.

Said was proved by the computations results that were obtained while the investigation of dependence of the informative signal (the flux of induction of the secondary magnetic field) on thickness of nickel coatings on bases with different magnetic properties when the value of a primary magnetizing field was different was being carried out. Fig. 3 shows the dependencies represented for the transducers with magnet energy about 15, 55, and 180 mJ.

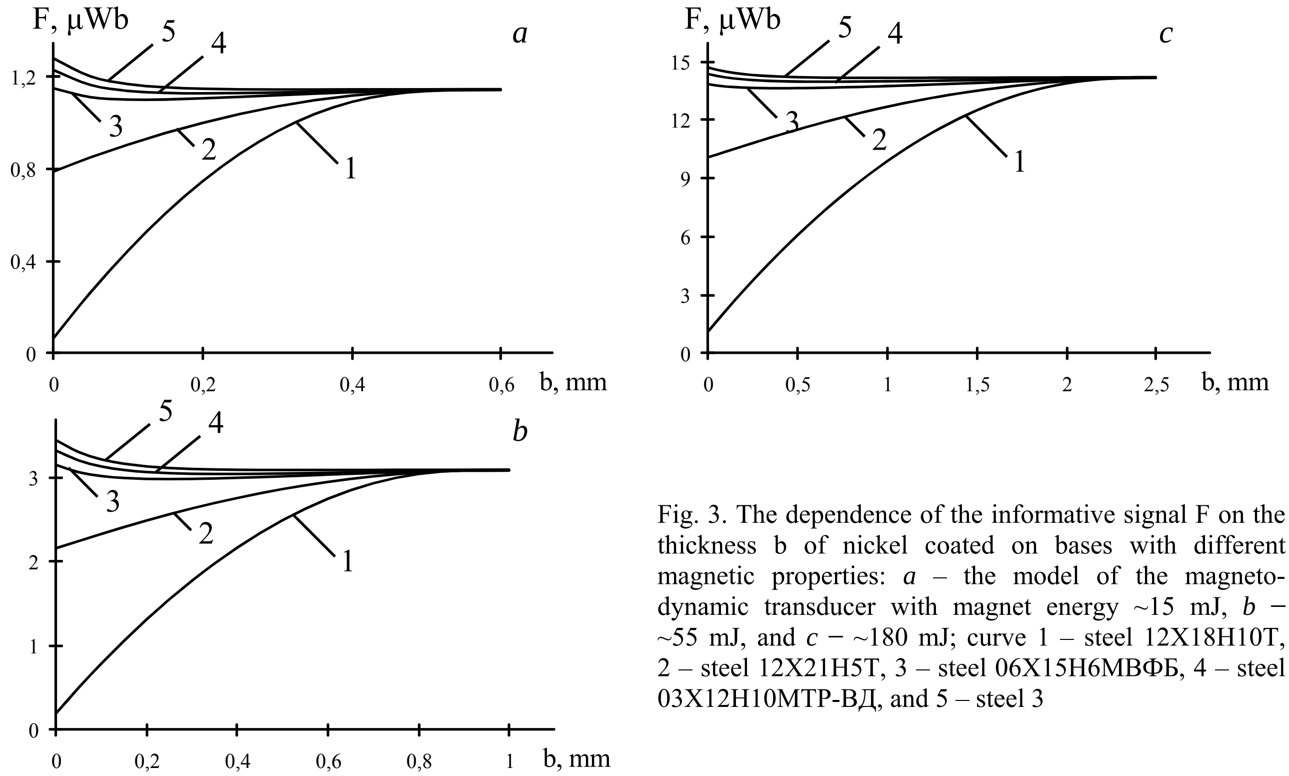

Fig. 3. The dependence of the informative signal F on the thickness b of nickel coated on bases with different magnetic properties: *a* – the model of the magneto-dynamic transducer with magnet energy ~15 mJ, *b* – ~55 mJ, and *c* – ~180 mJ; curve 1 – steel 12X18H10T, 2 – steel 12X21H5T, 3 – steel 06X15H6MBΦБ, 4 – steel 03X12H10MTP-BД, and 5 – steel 3

One can see that the sensitivity to nickel thickness depends on magnetic properties of the base in greater degree than on value of the magnetizing field. While properties of the base are strengthening, the measurement range is promptly narrowing, and when these properties are practically identical with properties of the coating, the testing of nickel thickness is on principle impossible irrespective of value of the magnetizing field. One can see also that if magnetic properties of nickel are stronger than properties of the base, the function F = f (b) at any magnet energy is monotonically increasing until the measured thickness comes up to depth of the informative area. Because this depth is proportional to value of the magnetizing field, in the case of the nonmagnetic base or very close to it, by the instrumentality of the transducer with the weakest magnet one can test nickel coatings by thickness no more than 350 μm while with the strongest magnet – by thickness approximately up to 1400 μm. If magnetic properties of the cover are stronger than nickel properties, the situation is changing on principle and the mentioned function from the decreasing curve quickly turns into the straight line parallel to the axis b. One can see that in this case, the sensitivity to nickel thickness with any magnetizing field is maximal only if properties of the base are strongest (steel 3). The computations show that on such base the transducers with magnet energy about 15 and 55 mJ provide testing of nickel by thickness up to 100 μm while the transducer with the biggest energy – by thickness no more than 20 μm. If one takes into account that with magnet energy no less than 180 mJ complete elimination of the main interfering factor (the structural state of nickel) is practically provided, the measurement range on bases with weak magnetic properties is no less than 1000 μm and the testing error is minimal. If properties of the base are stronger than nickel properties, while choosing the transducer the compromise between width of the range and value of the error is necessary.

The computations truth was proven by the measurements made on five discs, which remained after producing the ring specimens. During the measurements, nickel plates replacing galvanic nickel layers by different thickness were being imposed over the discs. Because the majority of the plates had been made by rolling with plastic deformation up to 30 %, and other – by milling, grinding, and polishing, the variation of structural properties of nickel was significant. As a measurement instrument, the magneto-dynamic transducer with magnet energy ~55 mJ connected to an electronic module of a thickness gauge was used. The results of the measurements are presented in fig. 4.

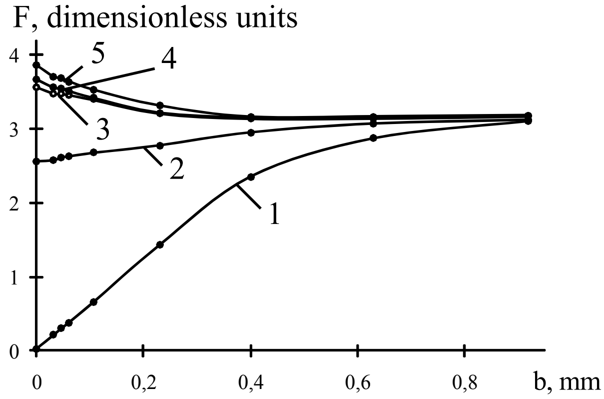

Fig. 4. The dependence of the signal F of the transducer with magnet energy about 55 mJ on the thickness b of the nickel plates imposed over the steel discs with different magnetic properties: curve 1 – steel 12X18H10T, 2 – steel 12X21H5T, 3 – steel 06X15H6MBФБ, 4 – steel 03X12H10MTP-ВД, and 5 – steel 3

Despite of clearances that were unavoidably between the plates and discs because of nonflatness of their surfaces, as well as variation of nickel structure, the experimental curves in their character are identical to the theoretical curves. On the one hand, it is the evidence of truth of the results that were obtained earlier; on the other hand, it indirectly affirms the possibility of partial elimination of nickel structure while using the transducer with the average magnet energy.

Basing on the received results, one can state that the magneto-dynamic method provides the testing of thickness of nickel coatings on bases with different magnetic properties, with the exception of the case when base properties and nickel properties are practically equal. On the one hand, the measurement range is defined by properties of the base; on the other hand, this range is defined by the magnetizing field value that is depended on parameters of the used transducer. If properties of the base are specified, the transducer creating the magnetizing field that has optimal value provides testing of nickel thickness in the maximally wide range.

The results given in the paper show the possibility of development of magneto-dynamic gauges for thickness testing of nickel applied on bases with different magnetic properties. These results can be used for transducers parameters optimization that is necessary for carrying out measurements in the defined ranges with the required accuracy.

REFERENCES

1. Useful model patent № 1030 BY, IPC G 01R 33/00. The Devise with Mounting Magnets for Nondestructive Testing / A. A. Lukhvich, A. L. Lukyanov. № u 20030022; patented 22.01.03; published 30.09.03 // Inventions. Useful Models. Industrial Models. Official Journal, 2003, № 3, Part 2. − P. 309.

2. A. A. Lukhvich, A. L. Lukyanov. Gauge for measuring thickness with bar magnets // NDT in Progress. Proceedings of IInd International Workshop of NDT Experts. – Prague, October 06-08, 2003. – P. 151-156.
3. A. A. Lukhvich, A. L. Lukyanov. New Magnetic Thickness Gauge Based on a Dynamic Method of Measurement of Secondary Magnetic Fields // 9th European Conference on NDT. DGZfP-Proceedings BB 103-CD – Berlin, September 25-29, 2006 − Poster 90, 6 p.
4. A. A. Lukhvich, O. V. Bulatov. Possibilities of the Magneto-Dynamic Method for Testing the Thickness of Two-Layer Coatings // Defectoscopiya, 2008, № 10. − P. 26-34.
5. A. A. Lukhvich, O. V. Bulatov, and A. L. Lukyanov. Possibilities of the Magneto-Dynamic Method for Thickness Testing of Coatings with Heterogeneous Properties (the Experiment) // Defectoscopiya, 2009, № 11. − P. 46-53.
6. V. F. Matiuk, A. A. Osipov. The Apparatus УИМХ for Measurement of Magnetic Characteristics of Soft-Magnetic Materials and Products // Defectoscopiya, 2007, № 3. – P. 12-25.