THE MAGNETO-DYNAMIC METHOD AND GAUGES FOR TWO-LAYER COATINGS TESTING

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The separate testing of two-layer coatings thickness is multi-parametric task, because irrespective of a measurement method, an informative parameter in general case is function of thicknesses of coating layers, their properties, and characteristics of measuring transducers. For the testing of two-layer coatings (a nonmagnetic layer on nickel coated on a nonmagnetic base), the optimal decision is the magneto-dynamic method of thickness measurement [1-5]. Its main advantage over other magnetic methods is that principle of measurement mechanically excludes influence of a primary magnetizing field on an informative signal. Consequently, a signal of a magneto-dynamic transducer is function of its characteristics, thicknesses of components of a two-layer coating, and nickel properties. It seems impossible to choose transducer parameters so that only one component of the coating determines the signal; it is necessary to have two transducers, which should differ in resolution for the components, and the difference should be considerable. The testing task becomes two-parametric if both transducers provide excluding or minimization of the informative signal component that depends on structural state of nickel. For realization of this condition, the selection of parameters of the transducers shall provide nickel magnetization close to the saturation magnetization, and the sufficient resolution too.

In the paper, the results of numerical computations of nickel magnetization distribution (including when nickel is under a nonmagnetic layer) subject to value of a primary magnetization field generated by a highly coercitive bar magnet of a transducer are presented. The dependence of the informative parameter (the flux of induction of the secondary magnetic field) on thicknesses of nickel and nonmagnetic layers is investigated. The substantiation of ranges and errors of testing of two-layer coating components is given.

By means of the finite element method on models of magneto-dynamic transducers and nonmagnetic discs with one-layer nickel and two-layer nonmagnetic-nickel coatings (the schemes are presented in fig. 1), the distribution of module of nickel magnetization in a volume of an informative area depending on magnet energy (the product of specific energy of magnet material on its volume) was researched. The radial distribution was computed by averaging on all nickel thickness, the distribution on depth – along symmetry axis of disc model. In fig. 2 charts of nickel magnetization distribution when the nickel layer by thickness 1000 μm is under the nonmagnetic layer by thickness 150 μm and without this layer, and while magnet energy is different are presented.

According to the obtained data, the transducer with magnet energy about 15 mJ in the whole volume of the informative area provides magnetization which module on the average is $0{,}6\cdot10^5$ A/m, with the energy about 55 mJ – $1{,}1\cdot10^5$ A/m, about 180 mJ – $2{,}8\cdot10^5$ A/m. It is known that the nickel saturation magnetization is near to $6\cdot10^5$ A/m. Because main contribution into the informative signal is brought by the central part (its radius is approximately 8 mm) of the informative area, and magnetization of this part is close to the saturation magnetization, the transducer with magnet energy about 180 mJ provides maximum elimination of nickel structure influence.

The degree of structural properties influence on signal value (the magneto-dynamic method was used) depending on magnetization of the informative area was investigated experimentally. For this purpose, specimens of nickel with significant variation of its structure were used: galvanic nickel applied on nonmagnetic bases with use of different technologies (cold or hot electrolyte); nickel plates made by rolling (degree of plastic deformation is up to 34 %) or by milling, grinding, and polishing; fragments of industrial products with thick nickel coatings. Thereby the range of nickel thickness (15 – 995 μm) and the variation of the structural properties close to the maximum variation that can be on practice of the thickness testing of nickel coatings were ensured. The measurements with usage of the set of magneto-dynamic transducers with magnet energy about 15, 55, and 180 mJ, and one electronic module of a thickness gauge were made. The results obtained on 22 specimens of nickel are shown in fig. 3.

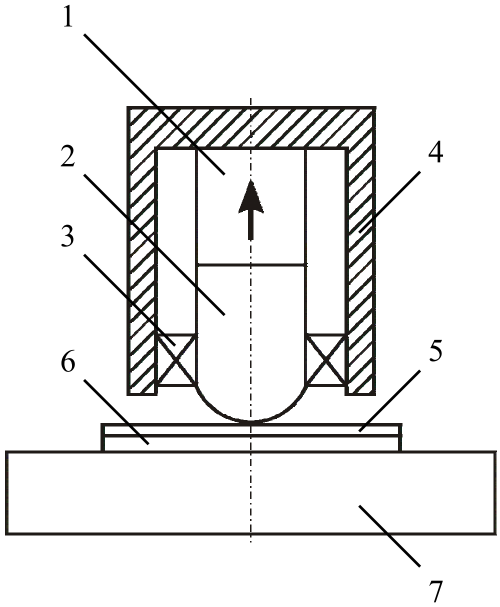


Fig. 1. A magneto-dynamic transducer installed on a testing object: 1 – a bar magnet, 2 – a pole tip, 3 – a multi-turn coil, 4 – a soft magnetic screen, 5 – a nonmagnetic layer, 6 – nickel, and 7 – a nonmagnetic base

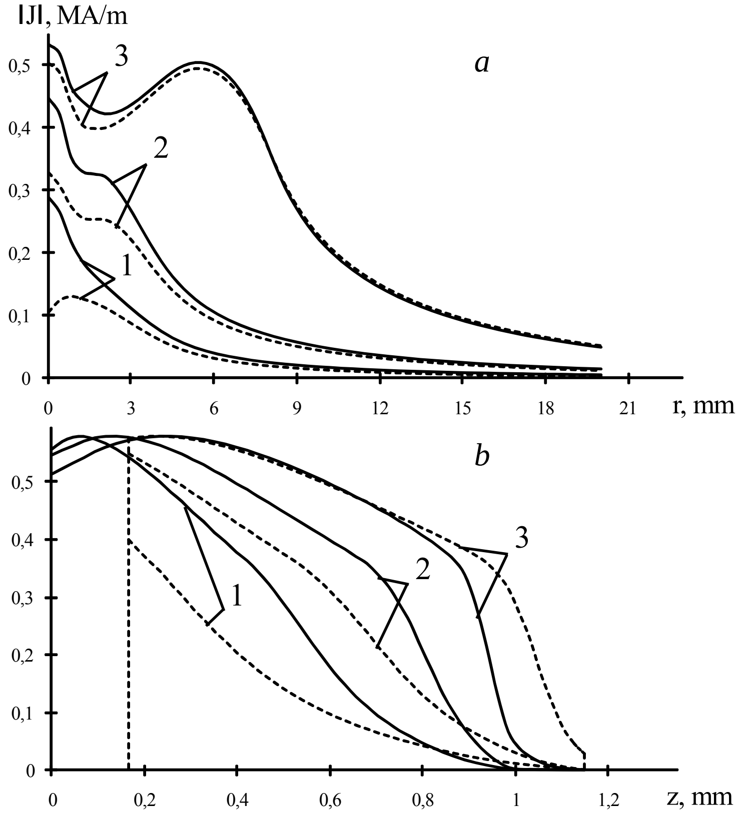
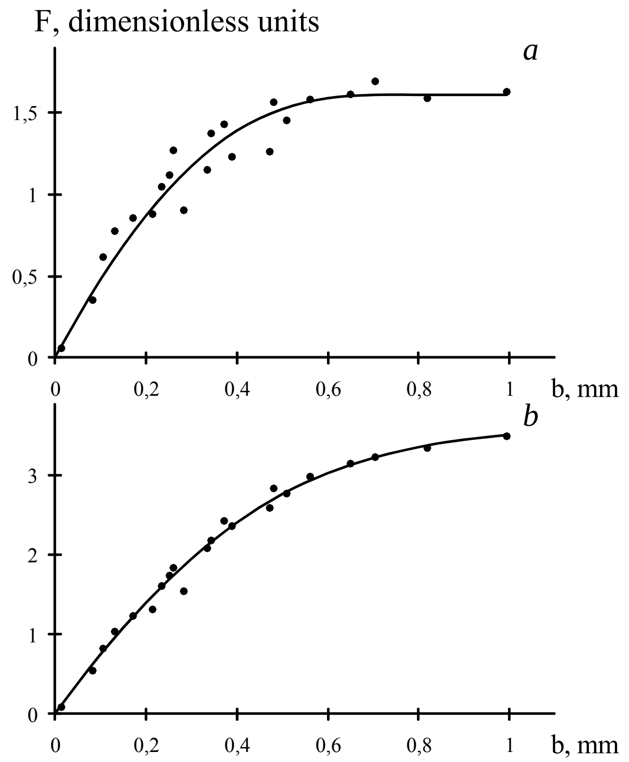


Fig. 2. The distribution of the module |J| of nickel magnetization: *a* – along the radius r, *b* – along the depth z; curves 1 – model of the transducer with magnet energy about 15 mJ, 2 – 55 mJ, and 3 – 180 mJ; the solid curves – uncoated nickel by thickness 1000 μm, the dotted curves – nickel under the nonmagnetic layer by thickness 150 μm



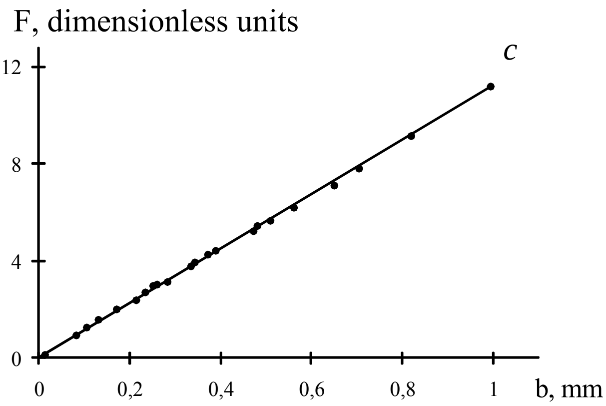


Fig. 3. The dependence of the signal F of a magneto-dynamic transducer on the thickness b of nickel with significantly different structural state: *a* – magnet energy is about 15 mJ, *b* – 55 mJ, and *c* – 180 mJ

On the assumption of the difference in character of the presented curves is determined by only structural properties of nickel, one can state that with strengthening of the primary magnetizing field the structural influence decreases, and when magnet energy is 180 mJ this influence already practically does not affect on the results of the nickel thickness testing. From fig. 3 follows also that simultaneously with the structure influence elimination the range of measurement widens. While using the transducer with the smallest magnet energy, the upper limit of the range is approximately 250-300 μm and one can test nickel coatings only with the same properties. While using the transducer with the biggest energy, the measuring range is more than 1000 μm, and nickel structure practically does not influence on the testing results.

Under the table 1, one can judge about the testing accuracy that is supplied with the magneto-dynamic transducer with magnet energy ~180 mJ.

Table 1. The results and error of measurement of thickness of nickel with different structural state

Method of specimen producing	True thickness of nickel, μm	Measured thickness of nickel, μm	Measurement error, %
Laboratory galvanics	15	14,5	3,3
Laboratory galvanics	42	42,7	1,7
Laboratory galvanics	84	81,4	3,1
Industrial galvanics	126	128	1,6
Industrial galvanics	135	133	1,5
Milling, grinding, and polishing	285	293	2,8
Industrial galvanics	298	291	2,3
Rolling (deformation is 30 %)	300	303	1,0
Industrial galvanics	320	317	0,9
Rolling (deformation is 15 %)	410	430	4,9
Rolling (deformation is 17 %)	470	477	1,5
Industrial galvanics	515	537	4,3
Industrial galvanics	730	756	3,6
Industrial galvanics	820	805	1,8
Milling, grinding, and polishing	995	998	0,3

One can see that the error is no more than 5 %. Further will be shown that there is a possibility of thickness testing of nickel under a nonmagnetic layer with the maximum error ~10-12 % irrespective of layer thickness that is up to 250 μm.

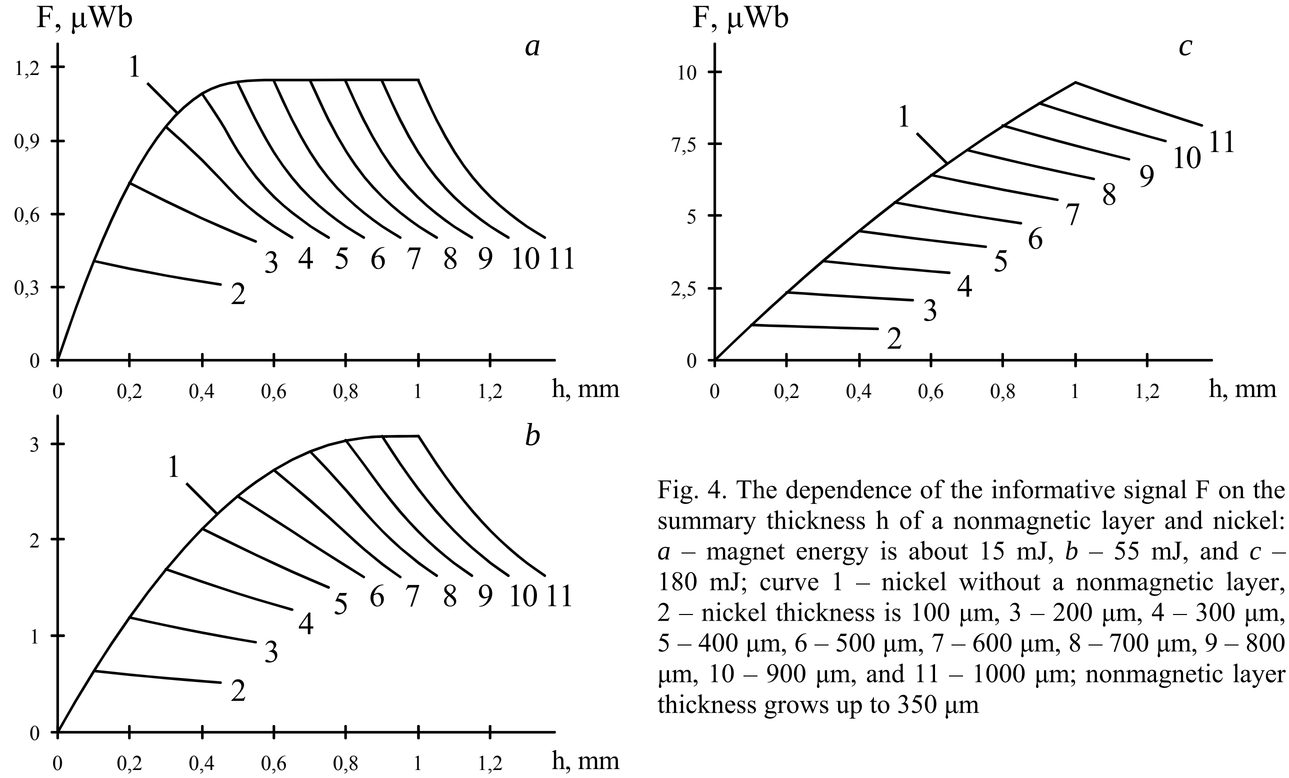


Fig. 4. The dependence of the informative signal F on the summary thickness h of a nonmagnetic layer and nickel: *a* – magnet energy is about 15 mJ, *b* – 55 mJ, and *c* – 180 mJ; curve 1 – nickel without a nonmagnetic layer, 2 – nickel thickness is 100 μm, 3 – 200 μm, 4 – 300 μm, 5 – 400 μm, 6 – 500 μm, 7 – 600 μm, 8 – 700 μm, 9 – 800 μm, 10 – 900 μm, and 11 – 1000 μm; nonmagnetic layer thickness grows up to 350 μm

By computational way the dependence of the informative signal on thicknesses of components of the two-layer coating while the magnetizing field value is different was investigated. Thickness of the nonmagnetic layer increased up to 350 µm, nickel thickness – up to 1000 µm. In fig. 4 the charts of the dependence of the signals of the transducers with magnet energy about 15, 55, and 180 mJ on the summary thickness of both layers are shown.

From fig. 4 follows that while magnet energy is growing, the transducer resolution is increasing, and the range of measurable nickel thickness provided by the transducer is widening. About possibility of testing of nonmagnetic layer thickness, one can judge by curves 2-11 that for the all transducers, the decrease of the signal irrespective of nickel thickness is observed. For the transducers with magnet energy about 15 and 55 mJ, the sensitivity to nonmagnetic layer thickness substantially increases until the definite nickel thickness, after that it remains practically constant. For the transducer with magnet energy ~180 mJ, the signal value almost doesn't depend on the nonmagnetic layer by thickness up to 350 µm applied on nickel by thickness up to 600-700 µm, therefore the sensitivity to layer thickness considerably lower, than for any transducer with less magnet energy. Qualitatively these data are resulted in the following:

– when nickel thickness is definite and no less than 150-200 µm, transducers with magnet energy up to 55 mJ provide testing of nonmagnetic layer thickness up to 300 µm and more;

– the transducer with magnet energy ~180 mJ provides (with the definite error) thickness testing of nickel under a nonmagnetic layer irrespective of its thickness.

The possibility of thickness testing of nickel under a nonmagnetic layer is checked out by the results given on the table 2. The magneto-dynamic transducer with magnet energy ~180 mJ on specimens by different nickel thickness made measurements; application of nonmagnetic plates simulated the upper layer.

Table 2. The results of measurement of thickness of nickel under a nonmagnetic layer

Nickel thickness, µm	Thickness of a nonmagnetic plate, µm					
	24	46	76	125	201	265
	Error of measurement of nickel thickness, %					
152	1,3	2,5	3,3	5,2	9,8	12,4
230	0,7	1,6	2,7	4,6	7,5	9,8
330	0,9	1,9	3,3	5,9	9,9	13,3
400	1,2	2,2	3,4	5,1	8,0	10,4
530	0,8	2,0	3,5	6,0	9,7	12,9
630	0,9	2,1	3,6	5,6	9,3	11,2
750	1,1	2,2	4,0	6,4	10,1	13,5

It is clear that while nickel thickness is up to 700 µm and nonmagnetic layer thickness is up to 200 µm, the testing error is no more than 10 % that from point of view of the nondestructive testing practice is acceptable result.

The results presented in the paper show that by the instrumentality of two magneto-dynamic transducers that generate different by value magnetizing field, the testing of components of two-layer coatings in practically usable ranges of thicknesses is provided. During realization of functional inspection, nickel thickness in the places defined by the product technical documentation by the instrumentality of the transducer with big magnet energy before nonmagnetic layer application is being measured. In this case, the informative signal is function of only nickel thickness (nickel structure practically does not influence on the measurement results). Then by the instrumentality of the transducer with smaller magnet energy, nonmagnetic layer thickness in the same places after the layer application is being measured (nickel thickness was taken into account by means of gauge calibration). Thus, one can provide the highest measurement accuracy. While the testing of components of two-layer coatings is being made, if the functional inspection is impossible, the same sequence of operations by the instrumentality of these transducers is remaining, however the accuracy in this case is lower (first of all at the expense of the error of the thickness measurement of nickel under the nonmagnetic layer).

The results given in the paper allow optimization of parameters of magneto-dynamic transducers as well as evaluating of their metrological characteristics with regard to the practical tasks of testing of two-layer coatings components.

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