MAGNETO-DYNAMIC METHOD OF SEPARATE CONTROL OF A THICKNESS OF DOUBLE-SIDE CERAMIC-METAL COATINGS

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The common case is considered, when the depth of the information zone is more than thickness of the not magnetic basis, on which from two sides is put the weak magnetic coating. In this case informative signal is determined by thickness of the basis and coating as with one, and on the other side. With reference to magneto-dynamic method the way of separate measurement of thickness of a coating from each side is offered in view of their common influence on informative signal.

At magnetic thickness measuring of coatings the thickness of the basis in some times is surpasses thickness of a coating and depth of information zone of the primary transducer. In such conditions the informative signal is unambiguously determined by thickness of a coating. However there are cases, when the depth of information zone is more than thickness of the basis. For example, if such situation arises at the control of not magnetic coatings on the magnetic basis, it results in dependence of informative signal from thickness of the basis. If it is necessary to measure thickness of magnetic coatings on the not magnetic basis, at double-side coatings the informative signal will be function of thickness of coatings, their magnetic properties and thickness of the basis. Such situation takes place at the control of thickness of ceramic-metal coatings on not magnetic or weak magnetic materials of turbine blades. In the given message is offered the method of the thickness control of components double-side low-magnetic coatings on the magnetic basis. The task was solved by computer modeling. The accounts were spent on a method of final elements with use of the program Femme 3.3 with reference to method implementation in magneto-dynamic thickness gage of MTG type.

Advantages of the magneto-dynamic method [1-4] in comparison with other magnetic methods is, that the informative signal does not contain a component caused by primary magnetizing field. It is reached by that in the primary converter as a basic element the constant magnet with weak magnetic tip and motionless in relation to them multiple-turn coil is used. At rise of the converter above a surface of a product the pulse of a current is generated, which size is determined only by induction of a secondary magnetic field, than the wide range of thickness and high resolution of the method is provided.

The ceramic-metal coating represent a mix fine (up to 7 microns) particles of nickel and not magnetic ceramics. Such system is weak magnetic material, which magnetic permeability depends on concentration of nickel and is determined by the ratio:

$$\mu = \frac{V_C + 4 \cdot V_{Ni}}{V_C + V_{Ni}} \qquad (1)$$

where: V_C, V_{Ni} - volume of ceramics and nickel, respectively; 4- magnetic permeability of a sphere. In practice the mixes with the weight relation of nickel to ceramics from 3:7 up to 1:1 are used. For the control of such coatings has appeared effective the magneto-dynamic method. Thus a magnet and tip of the converter should have a diameter of 10 mm. The depth h_0 of information zone created by such converter, is close to size of 10 mm. Therefore at thickness d of the not magnetic basis there is less specified size, the informative signal is determined not only thickness of a coating h_1, on which the converter is put, but also thickness d of the basis and thickness h_2 of a coating from the underside.

Obviously, the solution of a task of separate definition h_1 and h_2 also cannot be found if to be considered unknown all parameters ($h_1, h_2, \mu_1, \mu_2, d$), on which depends informative signal. As a rule, in real conditions, are known thickness of the basis d and weight (volumetric) structure of a coating (consequently – permeability $\mu = \mu_1 = \mu_2$). In such case, the informative signal is necessary to consider as function of two variable - h_1 and h_2. Thus thickness of the basis and permeability of a coating play a role of parameters.

In view of the specified restrictions, the calculation of informative signal of the magneto-dynamic converter is carried out. To the parameter d (thickness of the not magnetic basis) was assign value: 2, 3, 4, 5, 6 and 8 mm. To the parameter h (thickness of a coating) was assign value: 50, 100, 150, 200, 250 and 300 microns. The magnetic permeability of the coating μ - 1,582, 2,079 and 2,372 (corresponds to average value of the weight relations 1:1 and deviation 10 %). Two cases - $h_1 = h_2$ and $h_1 \neq h_2$ are considered.

The results of calculation on influence of thickness of a coating h (case $h = h_1 = h_2$) on magnitude of informative signal for thickness of the basis $d = 2$, 5 and 8 mm are show in fig. 1, 2 and 3, respectively.

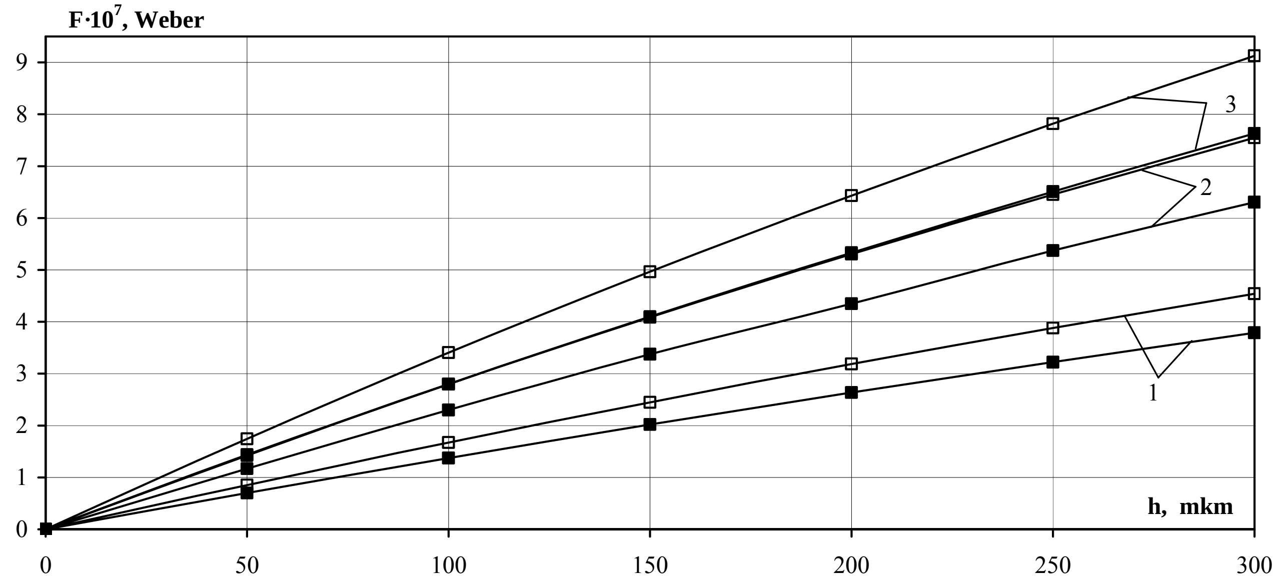

Fig. 1. The influence thickness of a coating h on magnitude of information.
$d = 2$ mm.
□ - double-side coatings, ■ - one-side coatings.

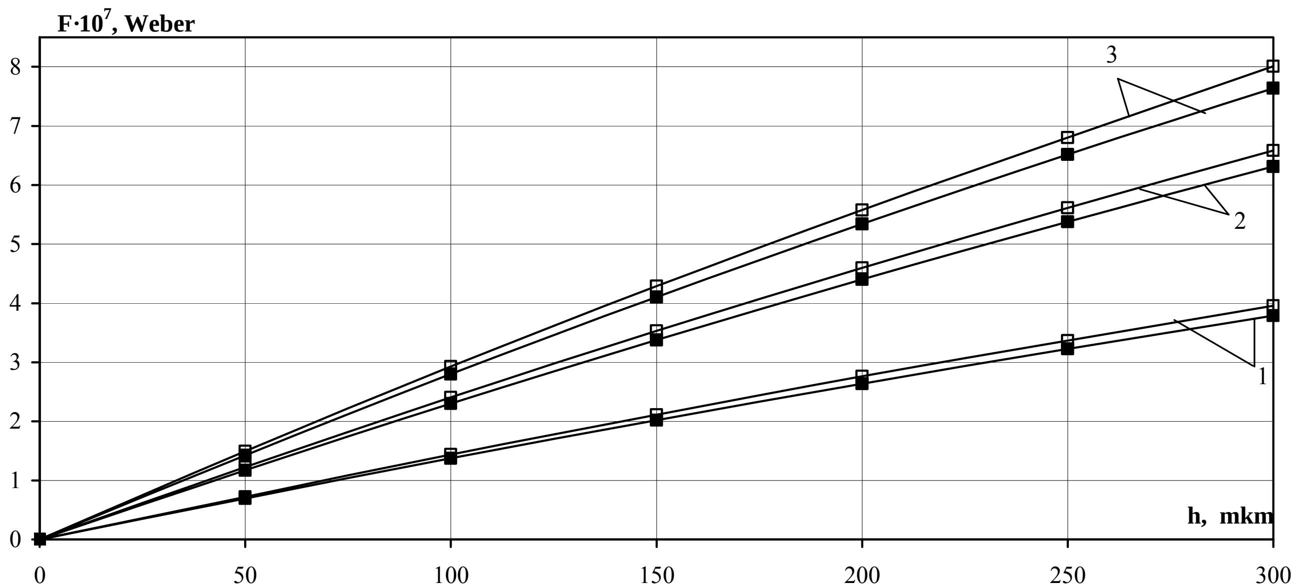

Fig. 2 The influence thickness of a coating h on magnitude of information.
$d = 5$ mm.
□ - double-side coatings, ■ - one-side coatings.

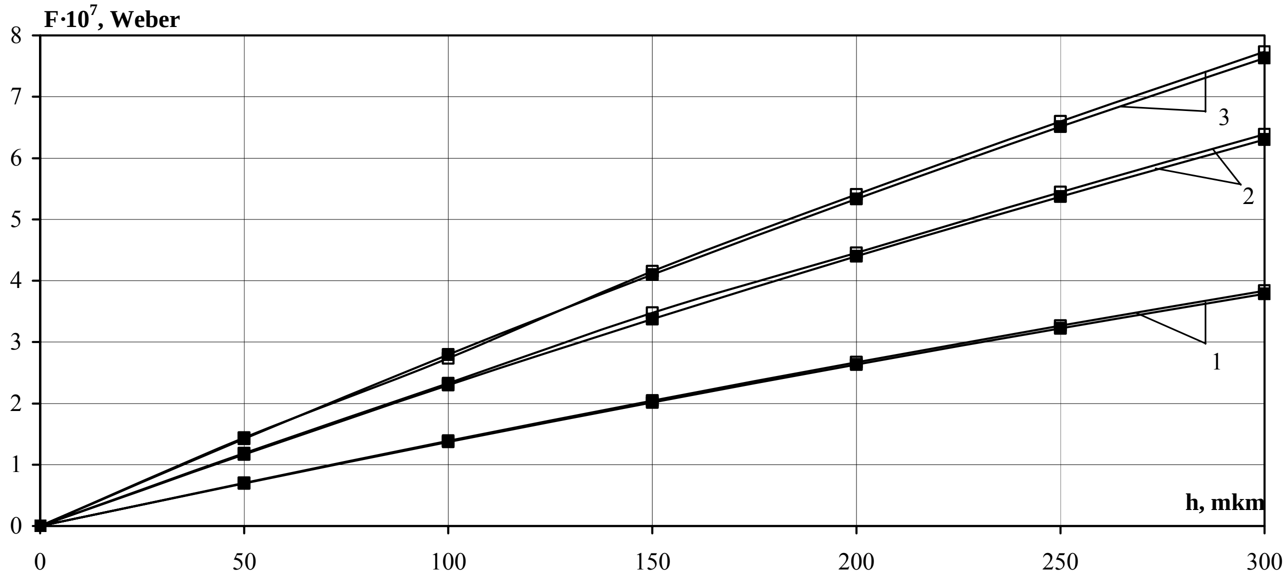

Fig. 3 The influence thickness of a coating h on magnitude of information.
$d = 8$ mm.
—□— - double-side coatings, —■— - one-side coatings.

Dependences for thickness d of the basis 3, 4 and 6 mm have similar character. On the figure 1 the common laws are visible: the change of a signal at the increase of a coating from the return side is appreciable, but decreases with increase of thickness of the basis; the absolute change of the signal grows both with growth of thickness of a coating, and with growth of its permeability; all dependences are close to linear and are well described by the formulas of a kind:

$$F = a_0 + a_1 \cdot h + a_2 \cdot h^2 + a_3 \cdot h^3, \qquad (2)$$

where F - magnitude of informative signal, which for the magneto-dynamic converter is determined by change of a flow of an induction through a measuring coil at removal of the converter from object of the control. The measuring coil in the magneto-dynamic converter is rigidly connected to the tip from soft magnetic material and is located on middle of its length. In the table 1 the values of factors a_i which are included in the equation (2), designed for systems with thickness of the basis 2, 5, 8 mm and coating with average value of magnetic permeability μ=2,079 are given. The factors received for systems, at which coating only on the one hand, are designated by one asterisk, two by asterisks - a coating from two sides.

Table 1

Factors a_i in equation (2)

d, mm	a_0^*	a_0^{**}	a_1^*	a_1^{**}	a_2^*	a_2^{**}	a_3^*	a_3^{**}
2	-0,0016	-0,0020	0,0240	0.0295	$-1\cdot 10^{-5}$	$-2\cdot 10^{-5}$	$-2\cdot 10^{-10}$	$4\cdot 10^{-10}$
5	0,0022	-0,0016	0,0238	0.0251	$-9\cdot 10^{-6}$	$-1\cdot 10^{-5}$	$4\cdot 10^{-10}$	$7\cdot 10^{-10}$
8	-0,0017	-0,0016	0,0240	0,0243	$-1\cdot 10^{-5}$	$-1\cdot 10^{-5}$	$3\cdot 10^{-10}$	$4\cdot 10^{-10}$

The similar results take place and for coatings with other values of magnetic permeability μ of the coating.

From the table 1 follows, that, with sufficient for practice as accuracy it is possible to consider the received dependences linear, as others composed by the values are less on the order. Thus factor a_1 for intermediate values of thickness of the basis can be determined under the formula:

$$a_1 = 0{,}0343 - 0{,}0027 \cdot d + 0{,}0002 \cdot d^2 \qquad (3)$$

If to be limited linear approximation, change of magnitude of the signal at the increase of coating with return side is possible to write down as:

$$\Delta F = h \cdot [tg\alpha_2(\mu) - tg\alpha_1(\mu)] \qquad (4)$$

Hence, as it is visible from (4), the increase of informative signal by a coating from the return side occurs both at the increase of its thickness, and at the increase of magnetic permeability.

The dependence of relative change of the informative signal from thickness h of a coating for the bases of different thickness d is given in the fig. 4.

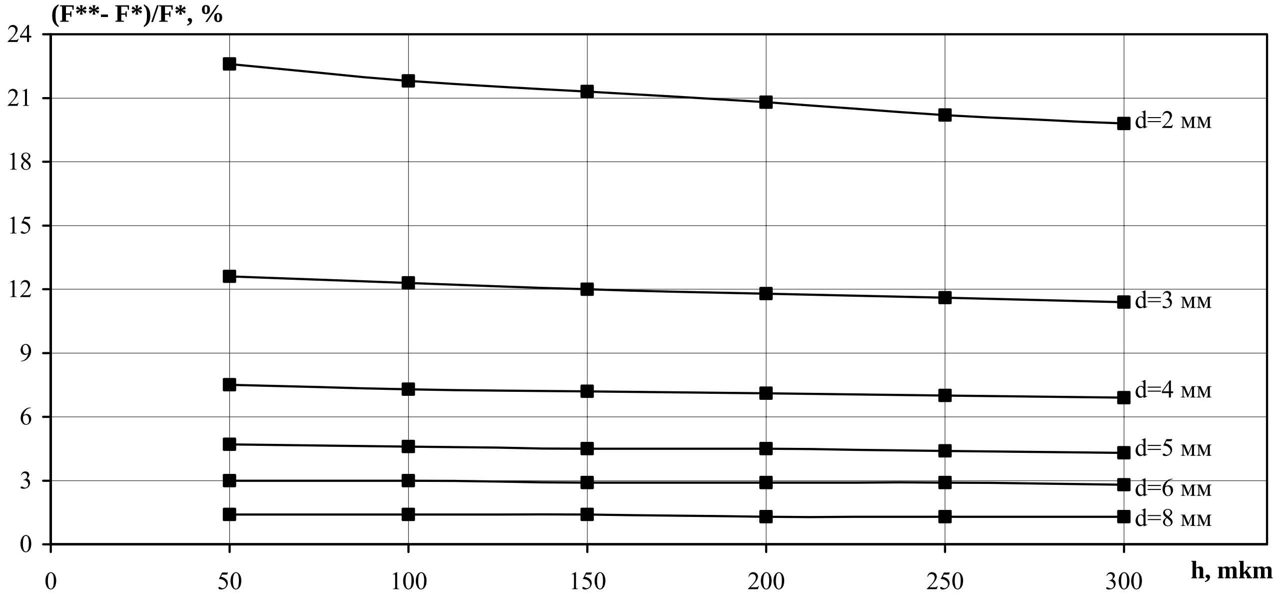

Fig. 4 The dependence of relative change of the informative signal from thickness h of a double-side coating for the bases of different thickness d.

From figure follows, that for $d > 2$ mm the relative change of the signal practically does not depend from h and decreases with growth d. For the thin basis ($d = 2$ mm) the change of the signal with growth h makes about 4 % at increase h from 50 up to 300 microns, and concerning a one-side coating the signal increases ~ 20 %.

The given results show, that if to use thickness gage, which calibration is carried out on the standards with a one-side coating, at measurement of thickness of a double-side coating is appear a regular mistake. However this mistake can essentially be reduced if to enter the correction into the indications of the thickness gage according to the formula (3).

Let's consider now common case - $h_1 \neq h_2$. Obviously, in this case the informative signal depends on what party of the test sample the converter is established. For case, when converter is established on side with coating thickness h_1 amount of the informative signal F_{12} is possible to present as:

$$F_{12} = F(h_1) + F(d, h_{12}) + F(d, h_2) + F(d, h_{21}), \qquad (5)$$

where $F(h_1)$ - the contribution to the informative signal brought by a coating of the thickness h_1 for lack of a coating of the thickness h_2; $F(d, h_{12})$ - the contribution to the informative signal brought by change of magnetization of a coating of the thickness h_1 by magnetic field a coating of the thickness h_2; $F(d, h_2)$- the contribution to the informative signal brought by a coating of the thickness h_2 for lack of a coating of the thickness h_1; $F(d, h_{21})$- the contribution to the informative signal brought by change of magnetization of a coating of the thickness h_2 by magnetic field a coating of the thickness h_1.

Similarly (5), in case of converter established on the side with the coating by thickness h_2, amount of the informative signal F_{21} will present as:

$$F_{21} = F(h_2) + F(d, h_{21}) + F(d, h_1) + F(d, h_{12}) \qquad (6)$$

The physical sense designations of variables in (6) are similar described above for variables in (5). From (5) and (6) follows, that $F(h_1, d, h_2) \neq F(h_1, d, h_2|_{\mu=1}) + F(h_1|_{\mu=1}, d, h_2)$. As show calculations, this distinction makes 2-3 %, depending on a ratio between sizes of thickness h_1 and h_2, and $F(h_1, d, h_2) < F(h_1, d, h_2|_{\mu=1}) + F(h_1|_{\mu=1}, d, h_2)$.

Physically it is connected that the thickness h_1 and h_2 of a coatings is many times less than radius of informative zone and consequently occurs mutual demagnetization: coatings of thickness h_1 is become demagnetized by tangential component of a field H_R of a coating of thickness h_2 and on the contrary.

For definition h_1 and h_2 is used method of calibration on reference samples. The converter is established serially on a coating by thickness h_1 and h_2 ($h_1 \geq h_2$), we shall have accordingly two signals: F_{12} and F_{21}. In the table 2 the results for calibration of system consisting of a coating by thickness h_1, basis by thickness of $d = 2$ mm and coating by thickness h_2 are given. Magnetic permeability of coatings $\mu = 2{,}078$. The sizes of information signals F_{12} and F_{21} for a case $h_2 > h_1$ can be received from the data contained in the table, rearrangement of indexes.

Generally, the contents of the table can be presented as system of the equations:

$$\begin{aligned} F_{12} &= f_1(h_1, h_2)\big|_{d,\mu} \\ F_{21} &= f_2(h_1, h_2)\big|_{d,\mu} \end{aligned} \qquad (7)$$

Table 2

Signals of transducer at different thickness h_1, h_2 of coating

№	h_1, mkm	h_2, mkm	$F_{12}\, 10^7$, Weber	$F_{21}\, 10^7$, Weber
1	300	0	6,307	1,496
2	300	50	6,534	2,514
3	300	100	6,752	3,706
4	300	159	6,976	4.740
5	300	200	7,168	5,724
6	300	250	7,365	6,661
7	300	300	7,556	7,556
8	250	0	5,375	1,268
9	250	50	5.608	2,398
10	250	100	5,834	3,492
11	250	150	6,051	4,533
12	250	200	6,262	5,521
13	250	250	6,465	6,465
14	200	0	4,399	1,132
15	200	50	4,639	2,169
16	200	100	4,827	3,270
17	200	150	5,096	4,316
18	200	200	5,312	5,312
19	150	0	3.375	0,788
20	150	50	3,625	1,932
21	150	100	3,862	3.040
22	150	150	4,093	4,093
23	100	0	2,300	0,535
24	100	50	2,558	1,686
25	100	100	2,802	2,802
26	50	0	1,168	0,272

Considering, for example $F_{12} = f(F_{21})$, we shall present the given results in system of coordinates F_{12}, F_{21}, then we shall receive some grid with quadrangular cells. For each cell of this grid the nodes are determined by amount of informative signals F_{12} and F_{21}, and sides – the value of thickness (h_1, h_2) one of coatings. Such calibration grid appropriate to the table 2, is given in a fig. 5.

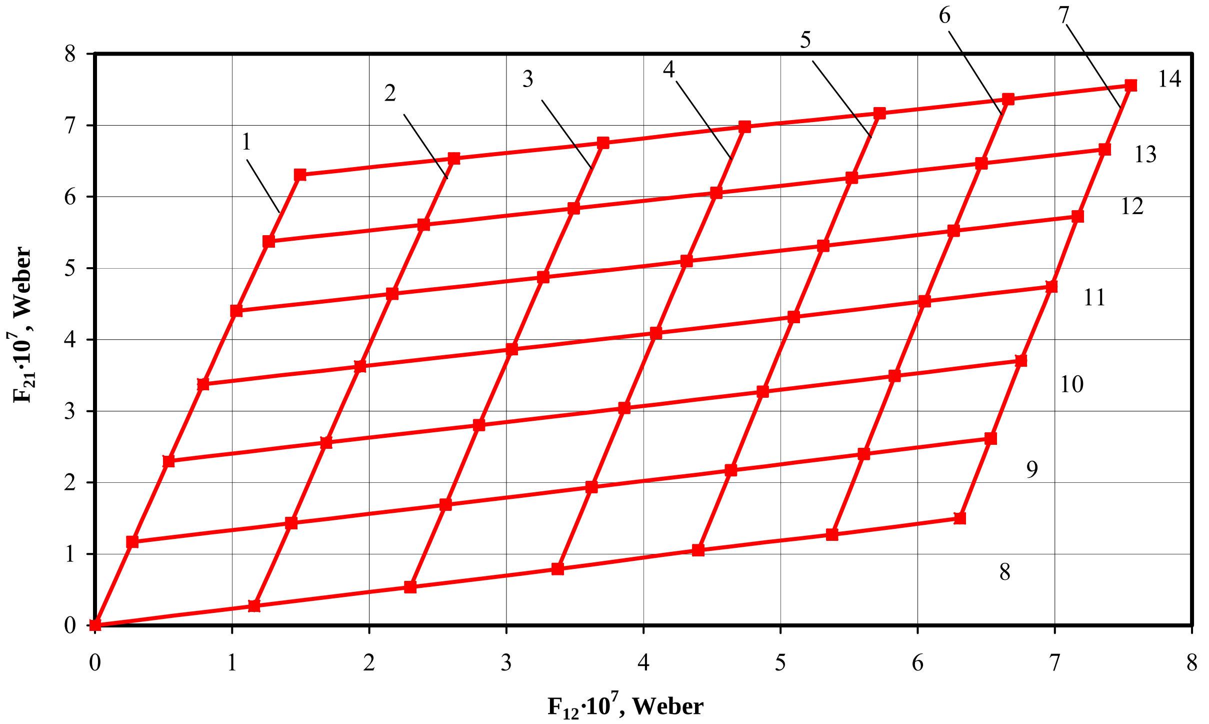

Fig. 5 The calibration grid.

Having such calibration and results of measurements F_{12}^x and F_{21}^x on researched object, it is possible to determine values of thickness of coatings h_1^x and h_2^x on each of the parties. For this purpose it is necessary in the beginning to determine a cell, in which the point T is hit with coordinates F_{12}^x, F_{21}^x. It is obvious, if to all cells to calculate distance:

$$D_i = \sum_{j=1}^{j=4} \sqrt{\left(F_{12}^j - F_{12}^x\right)^2 + \left(F_{21}^j - F_{21}^x\right)^2}, \quad (8)$$

its minimal value also will specify that cell with number i, to which the results received by measurements on object of the control is concern. Knowing a cell, by which the received point T(F_{12}^x, F_{21}^x) is carry, it is possible to find both values of thickness h_1^x and h_2^x coatings on the following algorithm:

- on coordinates of units of the chosen cell we find the equations of the sides of a cell, to take their pieces as a straight lines;
- spend through the received point T two crossed straight linees ($h_1 = const$ and $h_2 = const$), parallel the sides of the cells;
- solving systems of the appropriate equations, we determine coordinates of points of crossing of the lay straight lines with the sides of a cell (we shall designate them as M and N, L and K);
- knowing coordinates of points of crossing of straight lines with the sides of the cell, we find length of lines MN and LK, and as lines MT and LT;
- believing, that inside the cell of value of thickness of a coating change under the linear law, and that between this change and change of the appropriate signal within the limits of the cell there

is a direct proportionality, we receive the formulas for calculation thickness h_1^x and h_2^x of coatings from each side:

$$
\begin{aligned}
h_1^x &= h_1(M) + \frac{TM}{MN}\left[h_1(N) - h_1(M)\right] \\
h_2^x &= h_2(K) + \frac{TK}{KL}\left[h_2(L) - h_2(K)\right]
\end{aligned}
\qquad (9)
$$

It is necessary to note, that if the coating is one-side, the point inevitably gets on one of the external parties of a grid, and if the we have double-side coatings with identical thickness - the point gets on the main diagonal of a grid. Hence, the received calibration include all variants of possible ratio between thickness of coatings on the opposite sides.

As the signals of the converter depend on thickness of the basis and magnetic permeability of coatings, at the large assortment of objects of the control, such calibration are necessary having for various thickness of the basis and magnetic properties of coatings.

The number of reference samples for calibration can be reduced approximately twice, if for each thickness of a coating h_1 the condition $h_2 \le h_1$ is executed. In this case the calibration dependence will be limited to a triangle.

It is obvious, that the offered method of calibration and measurement of thickness of double-side coatings is enough universal and can be used at other methods of the control.

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