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STRUCTUROSCOPY OF COMPOSITE MATERIALS WITH INCLINED LAYERS USING ELECTROMAGNETIC FIELDS OF HIGH-FREQUENCY BAND

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ABSTRACT

Two-dimension model of carbon composite was investigated by a finite-difference method. We got the modulating characteristics of real and imaginary parts of vector-potential of eddy-current probe. The reverse problem – the determination the reinforcement ratio of investigated composite was solved.

***Keywords**:* Finite-difference method, Composite material, Eddy currents, Reinforcement ratio

1. Introduction

The composite materials using carbon fibres as reinforcing component with organic compound and processed by high temperature are widely used in aircraft and space industry as carrying constructions and heat-saving coverings. [1].
Mechanical and heat-physical properties of such materials greatly depend on volume concentration of carbon fibres, which is characterized by reinforcement ratio. Taking into account the fact that carbon fibre and processed by high temperature organic compound have conductivity properties it is worth while using noncontact eddy-current method. The layers of carbon fabric and a compound are inclined to external controlling surface of an article.
The inclination angle is different on different parts of the article. Often the external surface of the article has thin heat-resistant slightly conductive and dielectric covering.

2. The determination parameters of investigated composite

The finite-difference method was used for the solution the problem of structuroscopy. Two-dimension grid model of nonhomogeneous environment with alternating layers of different conductivity, inclined to the flat external surface, was created. Two-wire line was used as eddy-current probe. The step of grid is equal $0.25 \cdot 10^{-4}$ m. The width of grid area consisted material along the x axis is equal 1600 grid nodes; the height of grid area with material is 400 grid nodes. The two-wire circuit is lay above exterior surface by one grid step. The distance between current wire is $2 \cdot 10^{-3}$ m. The conditions of vector-potential decrease on grid area border are carrying out in area this size [1, 4].

The modelling program was created using the C programming language.

Reinforcement ratio æ determines part of reinforcement fibres in a volume of composite material according to thickness of layers of fabric and compound taken perpendicular to boundaries of layers as Fig.1.

$$æ = T_f / (T_f + T_c) \quad (1)$$

Were: T_f - the thickness of fabric layer, T_c - thickness of compound layer.

Six values of reinforcement ratio: 0.5, 0.56, 0.67, 0.71, 0.8, and 0.83 were preset for modelling. Inclination angles of layers of reinforcement fabric and of compound to external surface were taken equal $\pi/6$, $\pi/4$, $\pi/3$. The value of angle is measured according to deviation of layer boundaries from normal line to external surface that is angle 0 corresponds to vertical layers, which are perpendicular to surface. The ratio of conductivity of fabric layers and compound were taken equal to $\gamma = \sigma_f/\sigma_c = 2, 3, 5$. The value $k^2 = \omega\sigma\mu_0$ for fabric layer is equal to $4 \cdot 10^7$ 1/m^2.

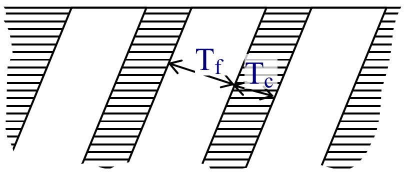

Fig.1: The determination of reinforcement coefficient.

As a result of calculations we got modulating characteristics of active and reactive components of vector-potential of eddy-current indicator while replacing discrete composite environment according to it. Modulation curves have periodical mode and consist of alternating impulses with different duration and amplitude. The example of modulation curves is shown on Fig.2.

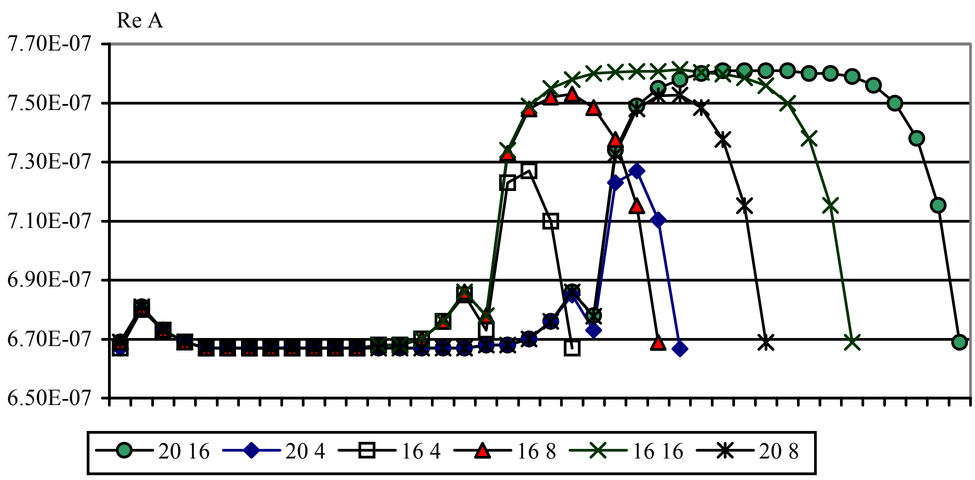

Fig. 2: Examples of modulation curves for composites with different reinforcement coefficient.

The same material but with different inclination angles of layers while being scanned gives us modulation curves of different period with similar as to their value real and imaginary parts of vector-potential.

If the outlet periods of layers of the same width onto the surface of investigated composite materials with the same properties coincide, the values of real and imaginary composites of vector-potential will coincide too.
The received characteristics give us the possibility to solve a reverse problem - to determine parameters of investigated composite. The reinforcement ratio æ, that is a part of carbon fibres in composite volume, determines, fist of all, firmness properties of an article made of composite material. The solution of reverse problem is very important for structure- and defectoscopy, because the properties of articles made of composite materials are being changed during the period of using the articles.
For determination of reinforcement ratio of investigated material we can use both real and imaginary parts of vector-potential. Modulation curves have periodical form with two impulse durations. The ratio of impulse width with longer duration to impulse period gives us the reinforcement ratio, because a carbon fabric occupies a bigger part than a compound in composite volume (in per cent).
The modulation characteristics with the following periods and impulses were received in the result of modelling with initial æ=0.56.

Table 1: The impulse widths of modulations characteristics example.

№ of the curve	Impulse period	Width of impulse 1	Width of impulse 2	Reinforcement ratio
1	39	22	17	0,564
2	50	27	23	0,54
3	79	43	36	0,544
4	36	20	16	0,555

Six values of æ: 0.5, 0.56, 0.67, 0.71, 0.8, 0.83 were taken for modelling. The reinforcement ratio of modelled composites is determined by the received modelling curves:

Table 2: Calculating the reinforcement ratio.

Angle	Period	Layer1	Layer2	Calculated reinforcement ratio	Given reinforcement ratio	Absolute error	Relative error
0							
	32	16	16	0,5	0,5	0,00000	0,000%
	36	20	16	0,5556	0,56	-0,00444	0,794%
	24	16	8	0,6667	0,67	-0,00333	0,498%
	28	20	8	0,7143	0,71	0,00429	0,604%
	20	16	4	0,8	0,8	0,00000	0,000%
	24	20	4	0,8333	0,83	0,00333	0,402%
30							
	35	17	18	0,4857	0,5	-0,01429	2,857%
	40	22	18	0,55	0,56	-0,01000	1,786%
	26	17	9	0,6538	0,67	-0,01615	2,411%
	31	22	9	0,7097	0,71	-0,00032	0,045%
	22	17	5	0,7727	0,8	-0,02727	3,409%
	27	22	5	0,8148	0,83	-0,01519	1,830%
45							

… continued

Angle	Period	Layer1	Layer2	Calculated reinforcement ratio	Given reinforcement ratio	Absolute error	Relative error
	43	20	23	0,4651	0,5	-0,03488	6,977%
	49	26	23	0,5306	0,56	-0,02939	5,248%
	32	20	12	0,625	0,67	-0,04500	6,716%
	38	26	12	0,6842	0,71	-0,02579	3,632%
	26	20	6	0,7692	0,8	-0,03077	3,846%
	32	26	6	0,8125	0,83	-0,01750	2,108%
60							
	71	35	36	0,493	0,5	-0,00704	1,408%
	79	45	34	0,5696	0,56	0,00962	1,718%
	53	35	18	0,6604	0,67	-0,00962	1,436%
	62	45	17	0,7258	0,71	0,01581	2,226%
	44	35	9	0,7955	0,8	-0,00455	0,568%
	53	45	8	0,8491	0,83	0,01906	2,296%

While comparing values reinforcement ratio calculated by modulation characteristics, with given value of æ we received their coincidence with a mean value of error of 2.2%. The biggest error value of determination the reinforcement ratio of 6.97% is noticed when $k^2=4*10^7$ 1/m^2 , $\gamma=5$, $\alpha=45°$. This shows that while using noncontact eddy-current method we can determine exactly enough the reinforcement ratio of an article made of carbon composite both while it is being produced and while it is being used.

3. Conclusions

Two-dimension model of carbon composite, consisting of alternating inclined layers of reinforcing fabrics and compound material was investigated with application of a finite-difference method. The solution was carried out in Cartesian coordinate. Two-wire line with harmonically changing current was used as two-dimension approach of eddy-current probe. Modulation curves of eddy-current probe were received by means of step by step moving of composite model relative to eddy-current probe. The reverse problem as for determination reinforcement ratio of composite - the property, determining firmness qualities of materials - was solved with the help of received modulation curves.

4. References

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