Microwave Electromagnetic Properties of Composite Radiomaterials Based on Magnetic Microwires

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***Abstract* – This paper represents the results of the research of electromagnetic response of composite radiomaterials containing glass-coated magnetic microwires of different diameters. The frequency dependence of the composite metal reflectance in the range from 10 MHz to 18 GHz is studied. The paper shows that the obtained samples have bulk resonance and there is an absorption increase within a narrow frequency range. With reducing the thickness of the sample the resonance shifts to higher frequencies. By varying microwire concentration in the composite it is possible to reduce the reflection coefficient at resonance to -48 dB or to get completely reflective material if overcoming the percolation threshold in cases of high filler concentration.**

***Index Terms* – Microwires, composite, microwave, reflection coefficient.**

I. INTRODUCTION

RECENTLY electronic devices working in the microwave range have significantly developed. We use them at work and at home. It is impossible to imagine people's life without them now. As a result of operating of many electronic devices simultaneously at one place, there is an increase in total electromagnetic radiation and interference which leads to unpredictable consequences for the operation of electronic devices [1] and human health [2]. In this regard, the urgent task is to create a new microwave radio materials and coatings to reduce the effect of microwave radiation [3].

Prospects in this sphere are connected with the development and application of composite materials. Composites are fairly simple to produce and can have specific properties unattainable for other materials (increased strength, flexibility, elasticity, etc.). Ferrimagnets, carbon nanomaterials [4] and microwires [5] are actively used as fillers for modern microwave composites.

Microwires and wires [6] are especially interesting for the manufacture of materials with radio absorbing properties. They have a number of unique properties in comparison with conventional powdered fillers [7]. These properties appear at very low concentrations of the filler active phase.

Microwires have high electrical conductivity and exceptional electromagnetic characteristics. They are determined by the composition of the metal alloy used in the production of microwires. Glass-coated microwires have excellent mechanical properties. They form a strong bond with any polymeric binder. As a result, the composite may have many functionalities that are needed for a variety of technological applications. Using glass-coated microwires it is possible to create firm or flexible structural radiomaterials.

Thus, the use of microwires helps to reduce weight of composites, to create firm, flexible and transparent structures and coatings. Therefore, in this paper we conduct a study of the electromagnetic response of the composite radiomaterial samples based on glass-coated magnetic microwires.

II. SAMPLES

A. Materials

Magnetic glass-coated microwires of the Fe-Co-B-Si alloy were selected as composite fillers. Microwires of two different sectional diameters (A-type and B-type) were used. They were obtained by continuous casting. Their basic characteristics are listed in the Table. I. Here *D* - is the diameter of glass-coated microwires, and *d* -is the diameter of microwires without glass-coated; ρ – is the resistivity of microwires.

TABLE I
CHARACTERISTICS OF THE MAGNETIC MICROWIRES

Microwire sample	*D*	*d*	ρ
	um	um	Ω ×m
A-type	22.4	15.7	1.37×10^{-6}
B-type	27.7	23.2	1.53×10^{-6}

Various options of the polymer binder were considered: silicone, varnishes, paints, epoxy resins, natural and synthetic rubbers. Epoxy resin was chosen because it has better adhesion properties for this type of filler.

B. Production of samples

Microwire, in general, is an extended, anisotropic structure. On the basis of microwires it is possible to get isotropic (finely ground microwire) as well as anisotropic samples (long segments). Wherein the electromagnetic parameters of this samples (the same microwire concentration) vary several fold [8]. Therefore, the method of manufacturing samples using long elements has a significant impact on their electromagnetic properties.

In our case, another scheme of sample production was chosen. It is a partial combination of the two methods mentioned above. The long stretches of microwires (tens of cm) are used as a filler. All components of the composite are weighed with the scales Shimadzu AUX-320 (error ~ 0.5 mg). Then the stretches of microwires are folded and put in special Teflon form distributed throughout its volume. After this a binder is poured in the form. Polymerization is performed at room temperature. Samples for measurement are fabricated in the puck shape of appropriate thickness. The basic structure of the samples is shown in Fig.1.

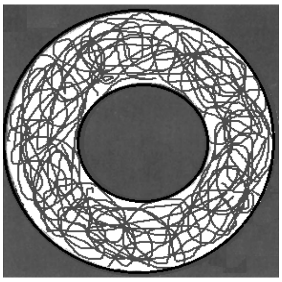

Fig. 1. The basic structure of the experimental samples.

Characteristics of the obtained samples are shown in Table. II. Production of samples, containing less than 3 wt.% of the B-type microwire (thicker) corresponding to the structure shown above, failed. We made two samples of different thickness: h = 1.70 mm and h = 2.70 mm. The accuracy of the thickness measurements is ± 0.02 mm.

TABLE II
COMPOSITE MATERIAL SAMPLES

Samples №	Consist (wt.%)		
	Epoxy	Microwire-A	Microwire-B
1	98.5	1.5	–
2	97	3	–
3	95	5	–
4	93	7	–
5	97	–	3
6	95	–	5
7	93	–	7
8	91	–	9

III. Measurements Technique

Measurements of electromagnetic response from radiocomposite sample were conducted by waveguide method. In this case, a coaxial measuring cell, with an outer diameter d_{out}. = 7 mm and an inner one d_{in}. = 3 mm. The instrument part of the meter is based on the vector network analyzer R4M-18 produced by the company "Micran ". We used the measurement scheme "reflection." Block chart of the measurement setup is shown in Fig.2. The method is based on a direct measurement of the reflection coefficient module (RL) from a flat layer of magnetodielectric located on the short-circuiting in the coaxial line. It is used to study the absorbing properties of weakly reflective materials.

Manufactured samples have the coaxial shape with the external diameter of 7.0 mm and inner diameter of 3.0 mm. They are precisely installed in the short-circuit measuring cell (without gaps and distortions). Electromagnetic response measurements were carried out at room temperature T = 23.0 ± 2.0 ° C.

The samples of composites containing magnetic microwires with different diameters were studied experimentally. The samples had different thicknesses and the weight content of filler.

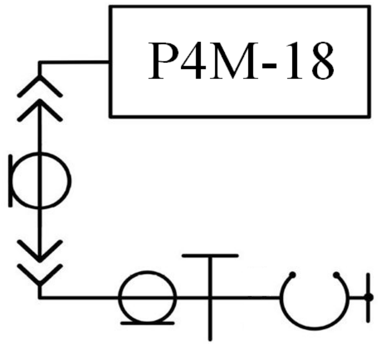

Fig. 2. Block chart of the experimental measurement setup, "reflection" scheme.

IV. Results and Discussion

Further there are results of measurements of the metal layer (RL) reflection coefficient of composites samples containing various concentrations of the A-type of microwire (Fig. 3).

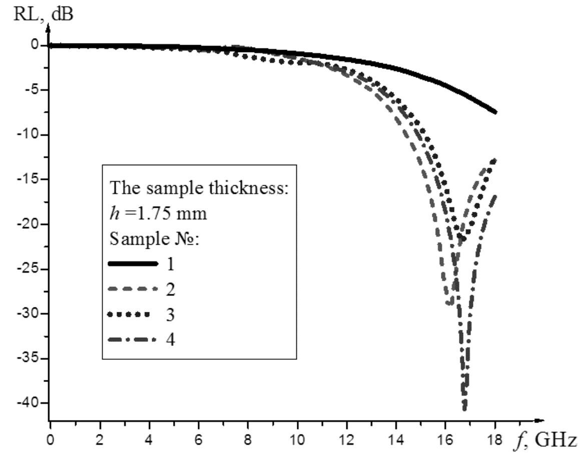

Fig.3. The electromagnetic response of the composite with different concentration of A-type microwire.

The charts have a maximum radiation absorption at frequencies from 16 to 17 GHz. Moreover, the level of absorption depends nonlinearly on the filler concentration. This sometimes occurs for this filler type [8]. When the concentration of A-type microwire is 7 wt.%, the level of reflected radiation from the metal sample at a frequency 17 GHz is only –40 dB. Extreme behavior of the reflection coefficient of the investigated materials is probably connected with the occurrence of quarter wave bulk resonance in the samples. To test this hypothesis measurements of different thickness samples are required. It should be noted that the width of the radiation attenuation band at the level of –10 dB is 3 to 4 GHz.

The following chart (see. Fig.4) shows the results of measuring the electromagnetic response of the microwires composite layer with different content of B-type.

Reflection losses for these samples are also extremes. But they are shifted in frequency range above 17 GHz and have smaller maxima values. This can be explained by the greater thickness and microwires concentrations, due to which the value of conductivity of composites increases at these frequencies. When the concentration of the filler is 9 wt.% the absorbance maximum practically disappears and the material becomes reflective throughout the range of frequencies. This is connected with overcoming the percolation threshold and the appearance of the material through conduction.

The two charts have a slight change in reflectance at around 8 – 9 GHz. It is more pronounced at higher concentrations of filler. This is due to the natural ferromagnetic resonance (NFMR) of the filler. According to the literature NFMR of the ferromagnetic alloy Fe-Co-B-Si ranges from 8 to 10 GHz.

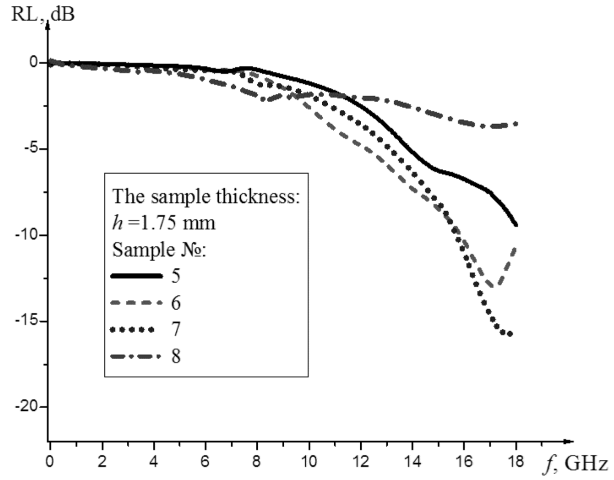

Fig. 4. The electromagnetic response of the composite with different concentration of B-type microwire.

The following chart (Fig.5) shows the values of reflection loss for composite samples with equal concentrations of A- and B-type microwires (samples number 3 and 6, 4 and 7).

All mentioned composites have extremes in the frequency dependence of the reflection coefficient. With an increase in the sample thickness of 1 mm they are shifted from 17 – 18 GHz (previous charts) to 11 – 12 GHz. This confirms that quarter wave bulk resonance arises in the samples. The frequency characteristics of the samples with the same concentration of microwires behave similar. The maximum level of radiation absorption is observed at concentrations of 5 wt.% (Samples 3 and 6). With an increase in concentration of microwire to 7 wt.% (4 and 7), the depth of the extremum decreases, but at a frequency of about 15.5 GHz a second maximum appears. Similar behavior in the reflection losses is observed in [8]. It is connected with the peaks of the real and imaginary parts of the complex permittivity. Due to this sample №4 bandwidth with RL < –10 dB is 8 GHz.

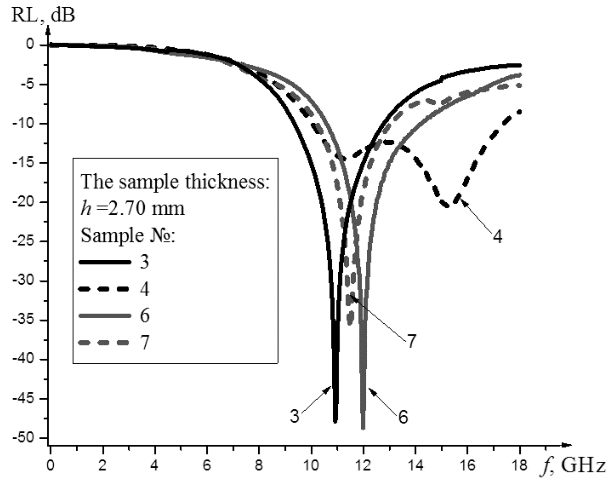

Fig. 5. The electromagnetic response of the composite A- and B-type microwires.

V. CONCLUSION

Composites based on glass-coated microwire from magnetic alloy Fe-Co-B-Si have the high values of reflection loss (48 dB), but in a very narrow frequency band. This is due to the appearance of bulk resonance at a certain thickness of the samples. At high concentrations of microwires we can observe small maximum associated with NFMR on the frequency characteristics of the RL around 8 – 9 GHz. When microwires concentration is of about 9 wt.% the percolation threshold is observed. When overcoming it composite becomes conductive and reflects electromagnetic radiation in the entire range of frequencies.

Results obtained for the sample №4, indicate the possibility of the use of composite materials in coatings for absorbing and shielding microwave radiation especially in the range from 10 to 18 GHz.

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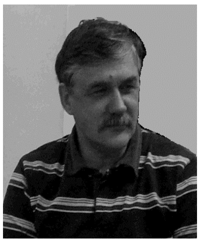

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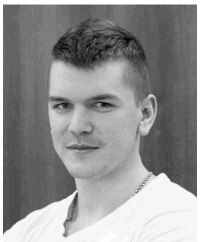

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