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Development the Adjusted Mathematical Model of Responses in the Nondestructive Testing Defectiveness Method Based on the Mechanoelectrical Transformations.

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Abstract. The improving version the responses mathematical model when using the method of mechanoelectrical transformations for nondestructive testing of defects in composite dielectric materials was examined. The refinement is conditioned by necessity of account of the frequency-dependent attenuation. For this has been used spectral approach: decomposition of excitation pulse in range and the formation of the amount each attenuate spectral component with the sample pulse response.

1. Introduction

An informative parameter in active nondestructive testing methods is interaction of excitation acoustic wave with testing object defects. Testing difficulties arise, because often defects (for example, cracks) have sizes considerably smaller, than excitation waves lengths. Therefore actual is to provide repeated reflection of excitation waves through testing object. At the same time the wave front repeatedly crosses defective zones and small deformations of front gradually accumulate.

As a result of it the registered response may differ significantly from a response from testing object with other defectiveness degree. To realize this, is necessary to provide the reverb mode, in which occur multiple reflection acoustic waves from the testing object borders. The reverb phenomenon is used in some acoustic testing methods [1-3]. On the same principle the mechanoelectrical transformations method (MET) was built [4].

In the MET method a testing object from composite dielectric material is excited by a short pulse of set form. The excitation acoustic wave impacts on mechanoelectrical converters that can be as double electric layers on dissimilar materials boundaries and also inclusions possessing piezoelectric properties. Due to changes the dipole moments of converters is formed the alternating electromagnetic field which may be registered by using external capacitance receivers. Using the MET method shows its high sensitivity to defectiveness and stress-strain state degree of dielectric materials [5-7].

For the study the MET method possibilities a mathematical model of responses in the ray approximation was developed [8]. On the model was shown that response parameters depend on system geometry: the excitation device – a sample – the signal receiver, from a sample parties ratio in the parallelepiped form from the location of the mechanoelectrical transformations sources.

In a narrow frequency strip the spectral and temporary responses characteristics of model and real testing objects with small defectiveness in the experiment identical geometry conditions were similar

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that testifies applicability of the ray approximation when researching on mechanoelectrical transformations method and possibility the mathematical model use as a standard for comparison of defectiveness and stress-strain state degree for real testing objects. However in a wide excitation spectral band the rather big difference between really obtained data and calculated ones by the mathematical model is observed. The reason for this is that the mathematical model does not take into account the spectral components frequency-dependent attenuation of excitation wave at its passing through the sample.

2. Modeling

A pulse mechanical excitation has rather wide range even in the conditions a radio pulse with harmonic filling. The high-frequency components of an excitation acoustic wave in the passing process by a sample because of internal friction attenuate faster than low-frequency inverse proportion to a square of frequency [9].

The harmonious signal attenuation from time t at a given frequency f0 is described by the following formula:

$$A(t) = A_0 \cdot \sin(2 \cdot \pi \cdot f_0 \cdot t) \cdot \exp\left(\frac{-t}{\tau(f_0)}\right), \quad (1)$$

where A_0 –a harmonic wave amplitude in an excitement point; $\tau(f_0)$ – an attenuation time constant for a given frequency.

$$\tau(f_0) = \frac{1}{f_0^{\,2} \cdot k}$$

k – constant multiplier;

Changing the frequency spectrum of the excitation pulse from the passage of time on the model requires a modification of the mathematical model, which would make it an adequate by the real of attenuation processes.

The response of sig_i is formed by convolution to the sample pulse characteristic h_i and temporary realization of a excitement signal s_i:

$$sig_i = \sum_{j=0}^{i} h_j \cdot s_{i-j}, \quad (2)$$

The following procedure of the accounting of spectral components attenuation was considered:

1) decomposition a form of an mechanical excitation pulse in a row of Fourier;
2) each harmonic component is represented in the form of attenuated harmonica;
3) its convolution with impulse response characteristic of the mathematical model is performed;
4) summarize all harmonious responses and to receive a full response in which frequency-dependent attenuation will be considered.

The problem is that in case of the attenuating harmonious signal its range expands according to a formula:

$$S_f = \frac{A_0 \cdot i}{\sqrt{2 \cdot \pi} \cdot \left(2 \cdot \pi \cdot (f - f_0) - \dfrac{-i}{\tau(f) \cdot k}\right)}, \quad (3)$$

where i – imaginary unit.

Consequently, appear the lateral spectral bands which are added to values of other harmonious components.

On the other hand, as seen in fig. 1 with frequency increase the amplitude of a specified harmonica decreases due to redistribution of energy in lateral frequencies. I.e. the competing processes take place: increases in amplitude of this harmonica due to replenishment from ranges of the next harmonicas and its reduction due to energy redistribution.

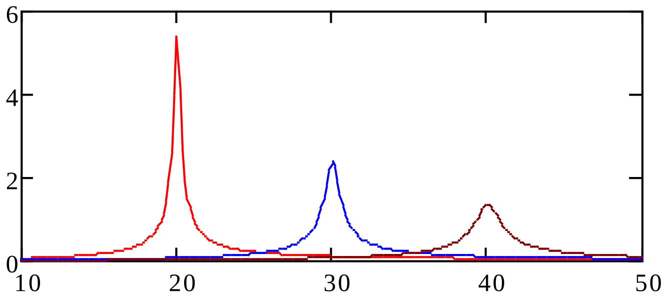

Figure 1. AFC of attenuated harmonic signals on the frequencies of 20, 30 and 40 kHz.

Let's consider a range of a single impulse. Its feature is that its amplitude-frequency characteristic (AFC) does not depend on frequency and, therefore, represents the straight line parallel to a frequencies axis. When passing a single impulse through a solid body its harmonious components will fade according to the equation (1).

Process of pulse signal attenuation in a solid body from time was simulated. The sum of the harmonious components attenuation of pulse excitation sig(t) on a formula (1) was calculated using the Mathcad:

$$sig(t) = \sum_{j=0}^{n} A_j \cdot \cos(2 \cdot \pi \cdot f_j \cdot t + \varphi_j) \cdot \exp\left[-t \cdot (f_j)^2 \cdot k\right], \tag{4}$$

where the A_j - the amplitude of the j harmonic expansions in the Fourier series; φ_j - the phase of the harmonic

Then the spectrum sig (t) was calculated using a Fourier transform. Fig. 2 shows the AFC of the (synthesized) spectrum.

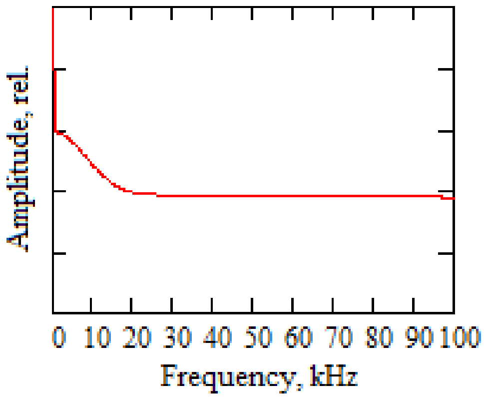

Figure 2 AFC of the synthesized range of a single pulse signal.

As appears from fig. 2 a total response of the spectrum attenuation harmonics of excitation single pulse it is also almost frequency independent at frequencies above 20 kHz. Raise of AFC at frequencies below 20 kHz is caused by limitation of selection length. It can be explained with the fact that the attenuated harmonious signal does not decrease to zero on the end of temporary realization, i.e. becomes discontinuous. Therefore there is Gibbs's effect distorting Fourier's decomposition. With increase in length of realization the error due to Gibbs's effect is displaced to the area of lower frequencies, showed calculation for mathematical model. Taking into account the specified circumstance it is possible to draw a conclusion on the acceptability of the algorithm of the accounting of attenuation frequency dependence for calculation by the mathematical ray model offered above [1]. Experiment by receiving a response from a concrete sample was carried out and calculation with use of the system same geometrical arrangement the impact device – a sample – the receiver of a signal and the same form of the excitation pulse was performed.

The electromagnetic response from the concrete sample for a given geometry of the experiment was received, as well as was calculated by the mathematical model using the same geometrical parameters and the same shape excitation pulse. The sample sizes - 100*80*60 mm3. The dot source of pulse mechanical excitation was located in the center of a lateral side, and a plate of capacitive receiver with size of 10*10 mm2 at the opposite side across from source. Frequency of digitization was 1 MHz (Δt=1 μs); duration of temporary realization - 3 ms.

3. Results and discussion

In fig. 3 the temporary characteristic of excitation pulse displayed. In fig. 4 – it's AFC (the continuous line). In the same figure the dashed line showed AFC of the excitation pulse synthesized taking into frequency attenuation.

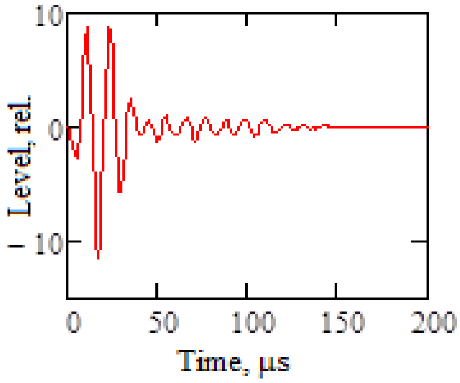

Figure 3. Temporary realization of excitation pulse.

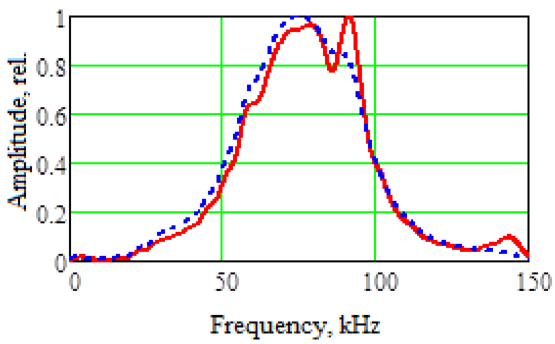

Figure 4. AFC of excitation pulse (the continuous line) and AFC of synthesized taking into frequency attenuation (the dotted line).

Apparently from fig. 4 real and synthesized AFC practically coincide.

For response calculation by the mathematical model was calculated the pulse characteristic of h(t) by the parameters of real experiment shown in fig. 5.

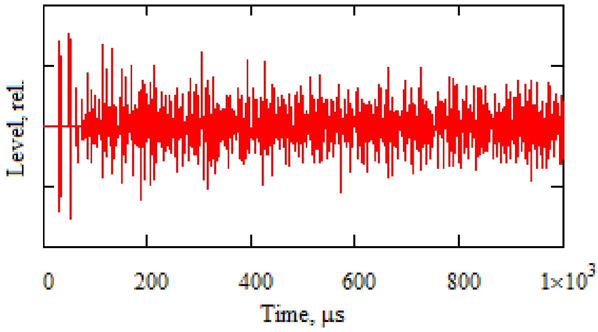

Figure 5. The pulse characteristic calculated by the mathematical model.

The pulse characteristic was calculated at model excitation with signal duration in one interval digitization time (1 µсек).

As seen from figure 5 in spite of the fact that the sample is excited by a spherical acoustic wave which level decreases in inverse proportion to distance from an excitement point, the pulse characteristic carries not decreasing character because energy of a signal does not dissipate in space, external concerning a sample, and is reflected from its borders and again participates in process of interaction with sources of mechanoelectrical transformations. I.e. in the specified model we neglect loss of acoustic energy at the expense of its exit from the sample boundaries.

The pulse characteristic represents imposing of a straight line and reflected from borders of a pulse wave with amplitudes inversely proportional to the passed way. Calculation of a response of res (t) was carried out on the following formula:

$$res(t) = \sum_{k=0}^{n} \exp(-f_k^{\,2} \cdot k \cdot i \cdot \Delta t) \cdot \sum_{j=0}^{i} a_k \cdot \sin(2 \cdot \pi \cdot f_k \cdot (i-j) \cdot \Delta t) \cdot h_j + \varphi_k) \quad , \qquad (5)$$

where n – number of the foldable harmonicas, which was chosen equal 450 that allowed to capture the range of frequencies from 0 to 150 kHz.

In fig. 6 temporary realization of the calculated response, and in fig. 7 – its AFC is displayed. In the same figure also shown excitation pulse AFC in the form of a dotted line.

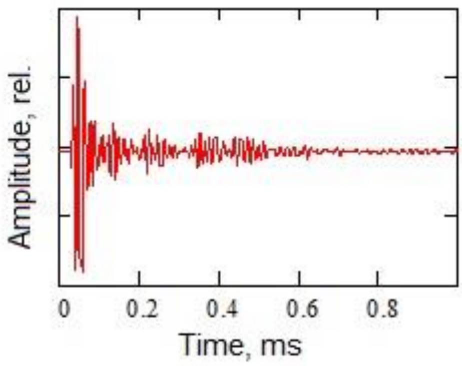

Figure 6. Temporary realization of the calculated response.

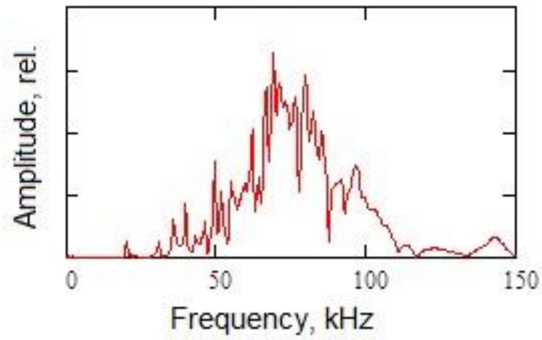

Figure 7. AFC of the temporary realization of the calculated response.

The comparative analysis of calculation results for model with a real response showed their qualitative similarity. Difference is caused, mainly, by distinction of internal structure. In model the sample is without defects and structureless whereas the real sample has a certain concentration of defects and has difficult multi-scale structure. Nevertheless the settlement response can be quite used as a reference point concerning which the assessment of change of defectiveness and structure under influences of external impact, for example, of mechanical loading, change of temperature and humidity in the conditions of monitoring of testing object.

4. Conclusion

The approach used to create the adjusted mathematical model, allows calculating responses that can serve as reference point for evaluation the defectiveness materials degree on experimental data.

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