SCATTERING WIDEBAND PULSE SIGNALS BY NON-SMOOTH SURFACES

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Abstract

Processes of scattering and reflection of wideband signals by non-smooth rough surfaces in the frequency range of 38 - 52 GHz have been investigated. Dependences of reflection coefficient for various non-smooth surfaces versus distance up to the antenna and the degree of roughness of the sample surface have been obtained experimentally. The influence of behavior and the degree of surface heterogeneity on the value of the reflection coefficient has been estimated using results of the measurements, the influence of spatial orientation of the scattering surface on amplitude of the reflected signal has been revealed.

Keywords: multifrequency methods, nondestructive testing, rough surfaces, radiopulse signal

1. INTRODUCTION

The multifrequency methods of nondestructive testing are widely used to determine parameters of multi-layered dielectric (sandwich) materials. One of most effective of them is the method of synthesizing the envelope of a radiopulse signal (MSERP) [1].

Composite dielectric structures are widely used as materials of solid-motor cases, thermal protection structures and sandwich radomes. Many of composite dielectric materials are made by a method of spinning of synthetic fibers thus the structures have rough surfaces. Due to surface roughness, these surfaces have reflectivity abilities which are considerably differ from smooth surfaces reflectivity.

The aim of this paper is experimental detection and estimation of the influence of presence of roughness on the front interface of dielectric structures under realization MSERP in the frequency range of 38-52 GHz.

2. METHOD OF SYNTHESIZING OF ENVELOPE OF RADIOPULSE SIGNAL (MSERP)

Method MSERP [1] is based on the examination of the synthesized envelope of a radiopulse signal, which is calculated by discrete inverse Fourier-transform of the frequency dependence of the reflection coefficient (RC) of a structure under investigation. This time-domain dependence allows us to identify explicitly peaks corresponding to reflection surfaces of the dielectric structure, to estimate permittivity of the measured material throw the absolute value of measured reflection coefficient, to estimate an electrical and geometrical thickness of dielectric samples by the time interval between the adjacent peaks of the time-domain signal under investigation.

For providing necessary resolution in time domain, the bandwidth of frequency tuning must be several gigahertzes but that is possible only in microwave range. The resolution of the method increases with growth of frequency bandwidth.

Under the solution of a problem of determination of parameters of multilayered structures using values of amplitude and positions of peaks of the synthesized time-domain signal, it is necessary to provide an opportunity of visual interpretation of the signal caused by reflection from two adjacent interfaces as two separate peaks.

Under testing of single-layered materials by MSERP, the method resolution of thickness is described by the relationship:

$$d = \frac{c}{2\Delta f \sqrt{\varepsilon}},$$

where Δf is frequency bandwidth, ε is permittivity of a material, c is light speed in empty space.

Improvement of accuracy of measurement of electrophysical parameters depends on a choice of surface reflection model for interpretation of obtained experimental data. Under investigation of reflection of rough surfaces the physical and mathematical model should take into account the presence of surface irregularities. Making a theoretical model of the reflection and scattering of pulse by rough surface is rather complicated; therefore for determination and estimations of influence of roughness, it is perspective to determine corresponding dependences experimentally.

3. MEASUREMENT SCHEME

Measurements have been carried out in a frequency range of 38 – 52 GHz with use of the measuring-calculating system (MCS) RIMCH-07 on the basis of IBM PC, which has been developed at the department of applied and computer radiophysics of Dnepropetrovsk National University [1]. Operating of the complex is founded on realization of the MSERP. The complex allows measuring the absolute value of reflection coefficient by amplitude of the peak of the synthesized signal in time domain.

The MCS is intended for remote research of multilayered dielectric structures including structures with rough surfaces. The complex includes measuring devices and the blocks developed specially for this measuring complex. The source of the microwave signal is generator R2-68. The sensing devices are the directed detectors of waveguide reflectometer from the complete set of panoramic SWR and attenuation meter R2-68.

Analog signal from reflectometer detector output is transformed to digital code by multichannel digital milivoltmeter of direct and alternating voltage. The special interface block serves for the interface of the digital milivoltmeter and the generator of signals with IBM PC. The measuring complex allows carrying out experimental research in real time mode.

The radiator of measuring complex is a pyramidal horn antenna of 46×46 mm aperture and 118 mm length. The samples under investigation were placed in certain distance from the aperture. The samples were made of smooth flat dielectric plates with various permittivity from $\varepsilon = 2.5$ up to $\varepsilon = 16$ with regular situated irregularities on the front surface. Degree of surface roughness was varied by varying the distance between adjacent irregularities. Measurements were carried out for every sample at distances from 25 to 45 cm, the distance between irregularities was from 1 up to 10 mm, averaging was carried out by results of 10-15 measurements. Results of measurements were kept in the form of frequency dependences of a square of the absolute value of the inserting reflection coefficient (IRC). For determination of reflection coefficient of dielectric structures obtained data of IRC was normalized on values of IRC of flat metal surface.

Experimental researches were carried out for two types of spatial orientation of the samples: "vertical" one when irregularities were been parallel to the direction of the vector of strength of the electric field of radiation and "horizontal" one when irregularities had perpendicular orientation to the electric field strength vector.

4. THE ANALYSIS OF EXPERIMENTAL DATA

For determination of the direct influences of the surface irregularities on scattering and reflection of wideband electromagnetic signals, the dependence of reflection coefficient from a regular grating made of dielectric cores with ε equal to 2.6-2.8 and diameter of 0.5 mm has been investigated. These cores were used as irregularities under construction rough surfaces. The dependences of the absolute value of RC for such structures versus the distance between dielectric irregularities for horizontal (1) and vertical (2) orientations of the sample, which have been located at distance of 35cm from the horn aperture, are presented in Fig.1. The interval between cores was varied from 1 up to 6 mm. The similar dependences were observed for other distances too.

The values of RC versus the interval between cores are in the limits of 0.010-0.033 for horizontal orientation of cores and 0.020-0.042 for vertical orientation correspondingly. From experimental data, it is evident, that the RC from array with vertically located cores is more than one for array with horizontal cores orientation. The minimal divergence of RC for vertical and horizontal orientations of cores is observed for the minimal interval between cores of 1 mm, it makes approximately 20-30 %. The maximal divergence of these values was equal to approximately 2 times and was observed for the interval between cores of 5 mm, that most likely, the effect was determined by diffraction phenomena at array when interval between cores tend to length of a wave of middle frequency of the operating frequency band. This effect decreases when the distance between the sample and a radiator increases.

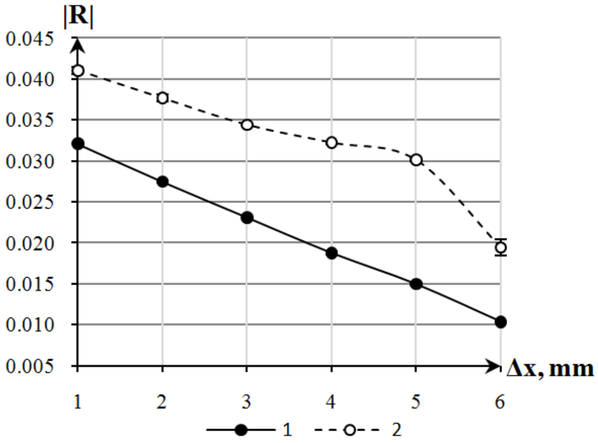

Fig. 1. Dependence of the absolute value of RC for a regular array of cores versus the interval between dielectric cores for horizontal (1) and vertical (2) orientations of the sample located at distance of 35 cm up to the aperture of a radiator.

Rough surfaces were prepared from flat homogeneous dielectric plates by putting parallel dielectric cores (irregularities) on front interface of the dielectric sample. That is equivalent of periodic concavities or cambers located on a flat surface.

The dependences of the absolute value of RC for rough structures on the basis of synthetic dielectric ceramics ST-16 versus the interval between dielectric irregularities for horizontal (1) and vertical (2) orientations of irregularities are presented in Fig.2. The samples were located at distance of 40 cm from the aperture of the horn radiator. The interval between irregularities was varied from 1 to 6 mm.

The dependence of the RC versus the degree of roughness is within the limits of 0.340-0.385 for horizontal orientation of irregularities and within the limits of 0.325-0.395 for case of vertical orientation. From dependences it is evident, that for main part of cases RC of samples with horizontally located irregularities approximately of 25% greater than one for samples with vertical orientation of irregularities. This effect is determined by phenomenon that at vertical orientation of irregularities, the electric field was more disturbed and more scattered by irregularities.

The extreme growth of RC up to values of 0.385-0.390 under the interval between irregularities of 3 mm are observed, most likely, the effect is caused by resonance diffraction phenomena under approach of the interval of the obtained lattice to length of the half wave λ/2 for middle frequency of the operating band. For distances of 30-40 cm from aperture to the sample the RC from samples with vertical orientation of irregularities exceeds the reflection from surfaces with horizontal irregularities. When the distance between irregularities exceeds 10 mm, influence of a roughness becomes imperceptible and the RC is approximately equal to the RC from smooth surface of ST-16 samples of 0.381. From experimental data it is evident the RC for samples with an interval between irregularities of 3 mm exceeds RC of the sample with smooth surface.

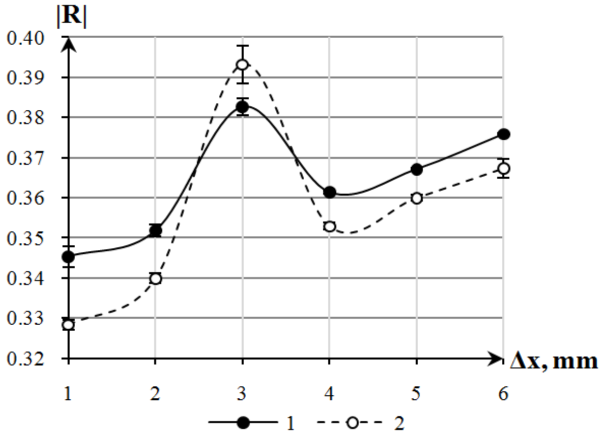

Fig. 2. Dependence of the absolute value of RC of ST-16 samples versus interval between roughnesses at horizontal (1) and vertical (2) orientations of samples, for distance of 40 cm up to the aperture of the radiator.

Similar researches have been carried out for rough samples on the basis of plexiglass. Unlike ST-16, permittivity of plexiglass and dielectric material for irregularities manufacturing is practically identical (ε = 2.5-2.8).

The dependences of the absolute value of RC of rough plexiglass structures versus the interval between irregularities for horizontal (1) and vertical (2) orientations of samples located at distance of 35 cm from the aperture of the horn are presented in Fig. 3. The interval between irregularities varied from 1 to 6 mm.

The dependence of the RC versus the degree of roughness is within the limits of 0.075-0.120 for vertical orientation of irregularities and within the limits of 0.098-0.160 for case of horizontal orientation. From dependences it is evident, that in all cases RC of samples with horizontally located irregularities approximately of 30% greater than one for samples with vertical orientation of irregularities. This effect is determined by phenomenon that at horizontal orientation of irregularities, the electric field was less disturbed by irregularities and focused by reflection from the surface of the sample.

As well as in the previous case for samples of ST-16, if the interval between irregularities become of 3 mm, extreme growth of RC up to values of the order 0.120 for vertical orientation of irregularities and 0.160 for horizontal orientation is observed. Under growth of distance between irregularities more than 10 mm, influence of irregularities becomes imperceptible and the RC approximately is equal to RC for smooth surface of plexiglass which is equal to 0.163.

Unlike samples of ST-16, the RC for samples of plexiglass with the interval between irregularities of 3 mm did not exceed the RC of smooth surfaces.

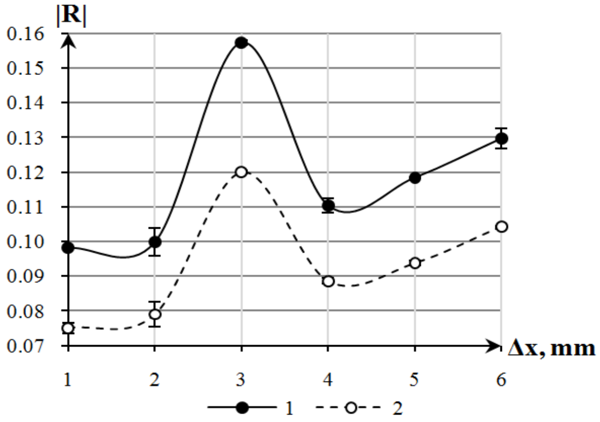

Fig. 3. Dependence of the absolute value of RC of plexiglass samples versus interval between roughnesses at horizontal (1) and vertical (2) orientations of samples, for distance of 35 cm up to the aperture

5. CONCLUSION

The received results allow us to estimate a change of value the measured reflection coefficient at presence of regular irregularities on a surface of products from dielectrics. These estimations can be useful to increase of reliability of nondestructive testing of products of modern mechanical engineering, for example, at research of properties and determination of parameters of the composite materials made by a method of spinning synthetic fibers.

REFERENCES

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