MEASURING THE REFLECTION OF ELECTROMAGNETIC WAVES FROM FOAM STRUCTURES OF VARIED FOAMING RATIO

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A specific multi-frequency technique for measuring the reflectivity of constantly collapsing foam structures of varied initial foam ratio is developed. A measuring and computing complex implemented the technique is used. It operates in the microwave range from 38 to 52 GHz. Dynamic foam structures with an initial foaming ratio of 55, 108, and 156 units in the form of flat-layered foam samples with a fixed thickness are under measurement. It is shown that the use of foam structure covering allows to reduce the reflection of electromagnetic waves from metal surfaces significantly. The obtained measurement results confirm the possibility of measuring dynamic foam structures, and this technique makes it possible to separate reflections from the front and back faces of the samples, which is very important for the study of the syneresis processes of the foaming liquid and the destruction of foam structures. The results are useful for studying the radiophysical characteristics of foams and for developers of new foaming agents for various applications where electromagnetic waves are used.

Keywords: microwave, millimeter waves, multi-frequency measurements, reflection coefficient, absorption, foam, foam structure, liquid foam.

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1. Introduction

Issues related to the propagation of electromagnetic waves in ordinary dielectrics have been sufficiently studied, covered in the widely known literature and various publications, in particular [1-4].

In recent decades, active research has begun on an unusual type of dielectric in the form of foam, which is a gas-liquid or solidified formation. This was due to the fact, that in 1955 G.F. Williams discovered the effect of increased emissivity of the sea surface covered with foam formations [5].

The amazing effect of the foam aroused great interest in connection with the emerging huge prospects of this phenomenon, both scientific and applied direction in many areas of life. In the USA, the former USSR and other countries, financial, technical, material, and human resources were allocated for research and development in these areas. New publications began to appear, including one of them [6].

Many new publications in the study of the propagation of electromagnetic waves of different ranges in foam structures bring a growing interest for specialists by A. Chithra, P. Wilson, S. Vijayan [7].

For example, S. Kharkovsky, F. Hepburn, J. Walker, R. Zoughi, J.T. Case, and M.A. Abou-Khousa solved many problems with foam coatings for modern space shuttle using millimeter waves [8, 9].

V. Nyagu in his research work draws the attention of readers to various issues related to the samples of foam structures that he solved. In particular, he pays great attention to equipment for the production and study of foams, modern methods of microwave quality testing of the used foam [10].

In papers [11, 12] the issues of propagation of millimeter and optical waves in foams were considered, as well as measurement methods and equipment used for studying foam samples.

"Foam caps" [13] have demonstrated formation of various foam structures on the surface of seas at wind speeds more than 7 meters per second.

It is very important to study the interaction of electromagnetic waves of various ranges with foam formations on the sea surface because it helps to monitor the movement of "foam caps" for weather prediction and traffic control of boats, ships, and submarines, which create huge traces of foam if they move. Such traces are well detected from aircrafts and from space.

At Dnepropetrovsk State University (DSU), now Oles Honchar Dnipro National University (DNU), research directed to study the propagation of electromagnetic waves in foams was begun in connection with the development, manufacture, and flight of the artificial Earth satellite "Kosmos 243".

It was the original study of the radiation characteristics of the Earth's surface, in particular, water areas where foam formations appeared, especially in areas of storms and in the case of movement of floating craft. This was especially important for the search for weather forecasting and for controlling the movement of various types of floating equipment such as ships and submarines.

Subsequently, some other foam research, technical and technological applications arose related to the safety of personnel and equipment, as well as to purely civilian applications in everyday life, construction, and industry.

We note some of the publications of the authors from DNU. So, V. Alekseev, O. Drobakhin and L. Filinskyy described the possibility of using the millimeter ranges in practical study of foam for possible applications [14].

Very important problems of the technique for measuring and calculating the dielectric properties ε and tan δ in foam plastic samples located in sections of rectangular waveguides one of the authors reviewed in [15].

In the microwave range of 8-12 GHz, values of the reflection and attenuation of electromagnetic waves were calculated in work [16] based on the experimental data. The samples of a multilayer structure of foam model were consisted of seven layers with different dielectric characteristics. The layers were of different thickness.

In the new paper [17] a study of the reflection characteristics of foam structures was made in a very wide megahertz range of electromagnetic waves from 1 to 1250 MHz for water foams with a foaming ratio of 10 to 85 units.

The purpose of this study is to develop a multi-frequency technique for measuring reflection coefficients from constantly decaying flat-layer foam samples of a fixed thickness with an initial foaming ratio of 55, 108 and 156 units. For this, it is necessary to use a measuring and computing complex of equipment, operating in the microwave range from 38 to 52 GHz [18] with implementation of Fourier holographic principle [19].

2.The main features of the foam

Foam is a liquid and gas mixture. Water foam, as a usual, is a static mixture of air and water. One of the main value of foam is the foaming ratio. As a rule, it is described as β. It means the ratio volume of the mixture (foam) to the volume of foaming liquid (in our case it is water). Foaming ratio is widely used to identify a foam structure, how light or heavy it is, how strong or brittle it is, how transparent or opaque it is to electromagnetic waves, how much it can reflect, transmit, or absorb them. True, the foam ratio value is more important for qualitative and quick estimations, but the real radiophysical characteristics of the foams, their quantitative values are quite difficult to determine.

Since the foam is constantly destroyed at a certain speed, it is necessary to measure the parameters of the foam faster than the structure of the foam changes. To do this, one must use the appropriate devices.

The foam is widely used in many technological processes, where it is necessary for constantly testing the physical-chemical and geometric parameters of the foam, as well as its foaming ratio β. It would be useful to measure the parameters of the foam remotely, without direct contact with the foam, for example, with the help of electromagnetic waves.

Also, for many problems, it is of interest to relate the foam ratio β with the dielectric parameters of foam **ε** and tg δ, and to test the foam structure by means of microwave radiation.

In case of speaking about dielectric properties of the foam, it should be noted that the main component of the foam, which determines its dielectric properties, is its foaming liquid in the form of a film frame.

3. Features of use of measuring equipment for foam research

One of the main requirements to measuring devices for studying foam structures is the short time of their measurements, so that the dynamic foam samples have no time to significantly collapse.

For the study of dynamic foam structures, an effective measuring and computing complex of the RIMCH type was developed [21], and methods of processing signals with a transition to the time (spatial) domain, which allow to separate the reflection from the structure itself from reflections in the measuring tract and created by objects in free space.

This complex makes it possible to carry out measurements in less than one second, which gives an opportunity for effective research of foam structures, because in such a short time, foam samples have no time to change significantly. Figure 1 shows a simplified diagram of the RIMCH complex for measuring the foam structures.

This measuring and computing complex implements a multi-frequency method of measuring the reflection coefficient in free space [22]. In it, the values of the ratio of the reflected signal to the “incident” were fixed in decibels and recalculated into the relative values of the entered reflection coefficient.

The “zero” value (in dB) was taken as the level when reflected from the metal plate when it was in plane A (the plane of the upper face of the sample) or in plane B (the plane of the lower face of the sample). The level of total absorption was fixed at the reflection from the matched load (-35dB). The studied foam sample was placed on a metal sheet (substrate) and its reflection in the studied frequency range was measured.

Thus, the frequency characteristic of the sample reflection was obtained with its subsequent transformation into the spatial domain (fast Fourier transform was used). On the computer monitor, it was possible to observe the location of inhomogeneities on the path of electromagnetic wave propagation from the reflectometer to the antenna and further to the metal substrate with the foam sample.

An antenna 120 mm long was used for measurements. The output size of the horn was (46 × 46) mm. For the preparation of foam, a foam tray with a base size (300 × 300) mm and a height of 80 mm was used. Before filling the tray with foam, calibrate microwave measurements were carried out using a metal plate along the upper plane of the cell (future sample) in plane A (Fig. 1). Next, the same metal plate was placed on the bottom of the tray (in plane B) for calibration along the lower boundary of the sample.

Foam samples were prepared using a 6% solution of foaming agent PO-6Al in water. The tray was filled with foam, resulting in flat layers of foam.

Microwave measurements were carried out for foam samples with ratio values of 55, 108, and 156 units at a fixed sample thickness of 80 mm.

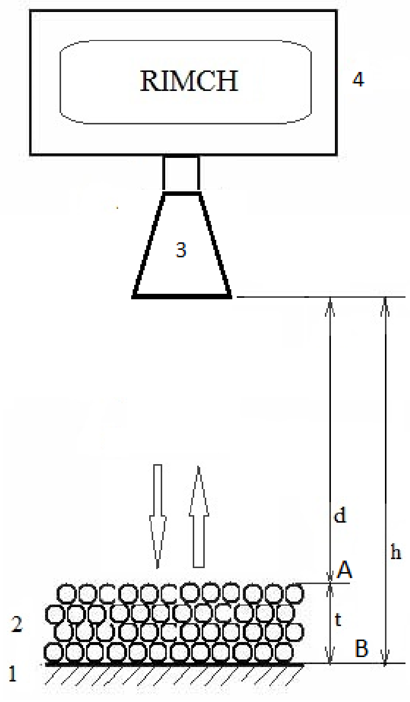

Fig. 1. A simplified scheme of the RIMCH measuring and computing complex for measuring foam structures:
1 – metal substrate;
2 – a sample of the foam structure;
3 – measuring horn antenna;
4 – RIMCH complex, which includes a frequency sweep generator from the 2-68 meter set, an indicator, a waveguide for supplying microwave radiation, a reflectometer, a computer, a digital-to-analog and analog-to-digital converter interface block.
Here:
t – is the thickness of the foam sample;
d – is the distance from the antenna aperture to the upper plane of the sample;
h – is the distance from the antenna aperture to the lower plane of the sample;
A – upper plane of calibration;
B – is the lower calibration plane.

4. Experimental results

Fig. 2, 4 and 6 show some results of measurements with the transformation of their frequency characteristics into spatial ones by means of a fast Fourier transform, and Fig. 3, 5 and 7 show graphs constructed from the results of processing experimental data.

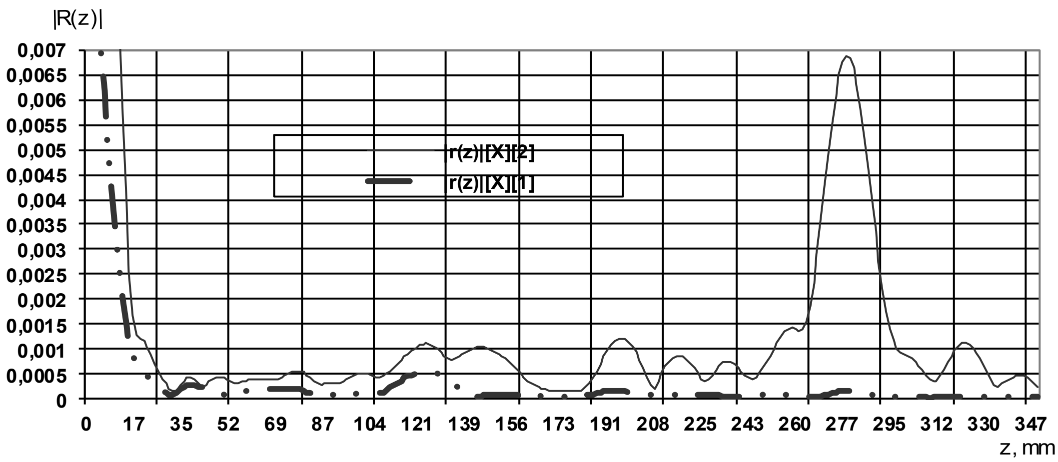

Fig. 2. Characteristics of the spatial dependence of the foam structure sample reflectivity (foam ratio 55). 1 – time of existence 30 s, 2 – time of existence 30 min.

Curve 1 (Fig. 2) characterizes the spatial dependence of the reflectivity of the foam structure sample with an existence time of 30 s, it can be seen from it that the value of the reflection coefficient was 0.00016 (peak at 200 mm).

This is about 840 times less than the reflection coefficient from a metal plate when placed at the same distance, the reflection amplitude of which was 0.134. With an increase in the time of existence of the samples, the reflectivity from the front boundary also increases and after 30 min takes the value 0.0012. Let us consider the reflection from the rear face after 30 min. It is equal to 0.0068 (curve 2), peaking in the region from 260 to 295 mm. This is almost 43 times greater than the reflection coefficient from a sample with an initial time of existence of 30 s.

In Fig. 3 curves 1 (reflection from the front face) and 2 (reflection from the back face) with an existence time from 30 s to 30 min demonstrate a rather smooth dynamics of liquid phase syneresis from a layer of the given foam structure (for a significant time of existence of the foam sample (more than 17 minutes), the reflection coefficients of this structure slightly swing around the average value).

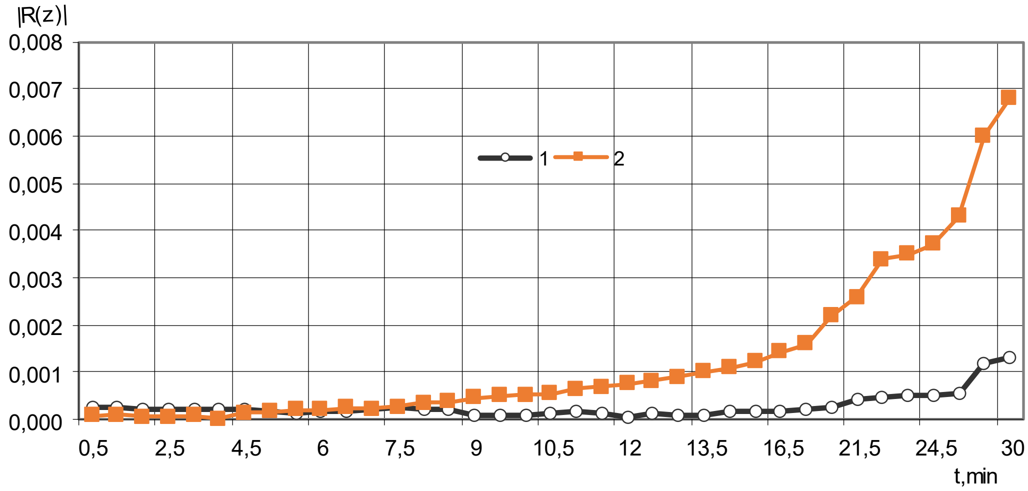

Fig. 3. Dependence of the reflection coefficients of the foam structure sample with a foaming ratio of 55 on the time of existence. 1 – reflection from the front face, 2 – reflection from the back face.

Insignificant breaks in the curve indicate that the thick layer of the foam structure is heavier and structural transformations in it proceed more spontaneously, more chaotically with sharp characteristic explosions of bubbles and their association into bubbles of a larger diameter.

The values of the reflectivity for the front and back faces of the samples are different: for the front face it is in the range of 0.0006 – 0.0014, and for the back face in the range of 0.0004 – 0.0068 during the studied time of existence of the foam sample.

For the initial lifetime of the samples (from 0.5 to 5 min), the reflectivity from the front face is somewhat higher than from the back face. This is because the electromagnetic wave attenuates along the path of propagation in the bulk of the sample. The attenuation is quite significant, therefore, against the background of noise, it is not always possible to clearly identify the reflection from the back face because the noise of the measuring path.

However, further after the interval from 5 to 7 minutes, the foam structure becomes more radio transparent, and it becomes easy to resolve reflection from the front and back faces of the sample.

Thus, the characteristic predominance of the reflection signal from the back face over the reflection from the front face becomes more obvious (Fig. 3).

Fig. 4 characterizes the spatial dependence of the reflectivity of samples of foam structures with a foam ratio of 108. Curve 1 (the time of existence of the foam sample is 30 seconds) shows that the value of the reflection coefficient = 0.0005. This is about 270 times less than the reflection coefficient from the metal plate at the front face of the sample.

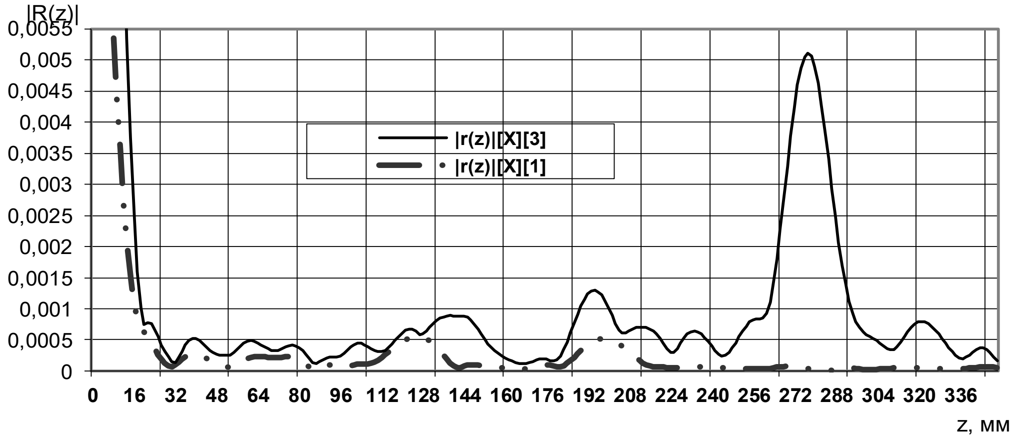

Fig. 4. Characteristics of the spatial dependence of the reflection coefficient of the foam structure sample (foaming ratio 108). 1 – time of existence 30 s, 3 – time of existence 30 min.

A separate representation of the reflection from the front (curve 1) and back (curve 2) faces of the sample is given in Fig. 5. Here the curves are like the curves in Fig. 3, however, the separation is not so sharp, it is noticeable only at the initial and final moments of time. This is due to the greater degree of radio transparency of the sample.

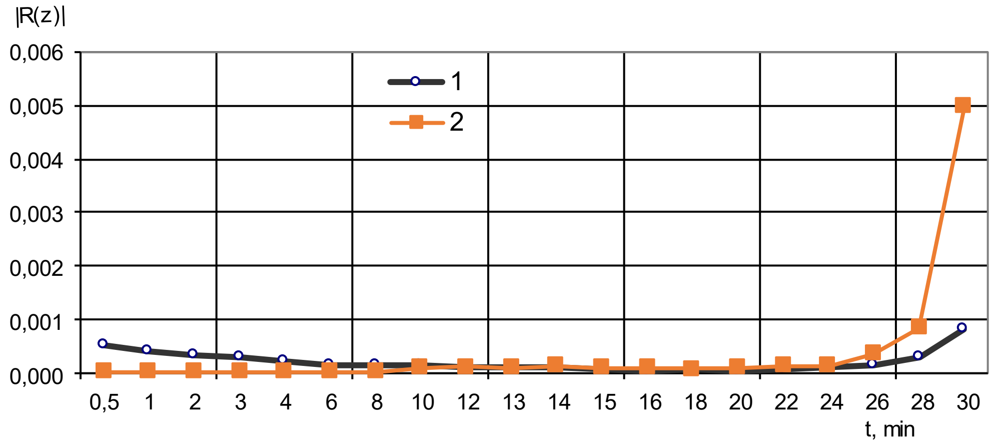

**Fig. 5. Dependence of the reflection coefficient of a foam structure sample with a foaming ratio of 108 on the time of existence.
1 – reflection from the front face, 2 – reflection from the back face.**

Now consider an even "lighter" foam structure with a magnification of 156. Fig. 6 characterizes the spatial dependence of the reflectance of a foam structure sample with a foam ratio of 156 at different times of existence. Curve 1 (time of existence 30 s) and curve 2 (time of existence 30 min) are almost the same. Within 30 minutes, the foam structure almost did not change, which indicates its high stability.

This is definitely the best option for the lightest in weight, the most stable in time and the most absorbing structure for the given range of electromagnetic waves from 38 to 52 GHz. It can be seen from Fig. 7 that the reflection from the sample is very small.

All that's left is the reflection from the front face, while reflection from the back face is so small that it is simply not fixed, and from the front face it decreased from 0.00045 to 0.00005.

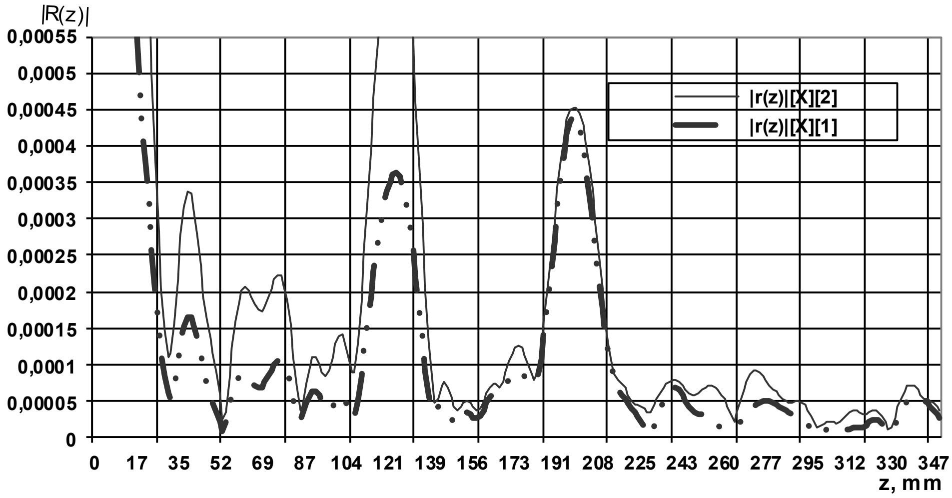

Fig. 6. Characteristics of the spatial dependence of the reflection coefficient of the foam structure sample (foaming ratio 156). 1 – time of existence 30 s, 2 – time of existence 30 min.

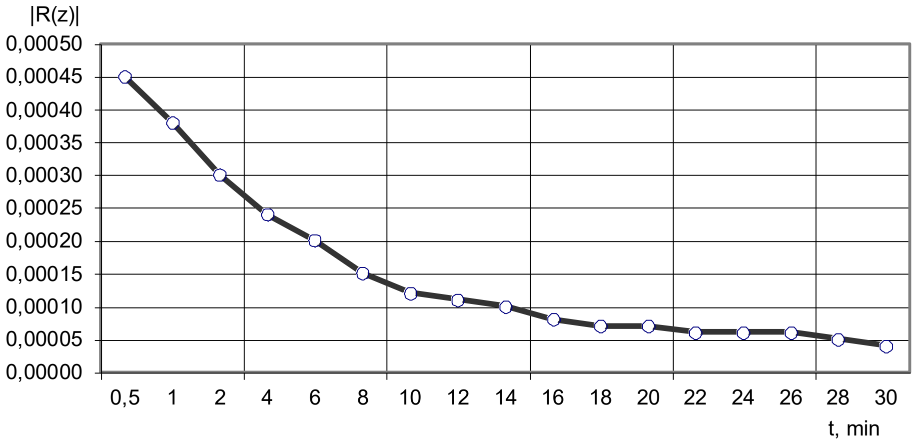

Fig. 7. Dependence of the reflection coefficient of the foam structure sample with a foaming ratio of 156 on the time of existence.

4. Conclusions

The results of the work will be useful for studying the radiophysical characteristics of foams and for developing new foam concentrates for various applications where electromagnetic waves are used, for example, both for protecting personnel from harmful electromagnetic radiation and for protecting metal objects from a radar detection.

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