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L. A. Filins'kyy*

Oles Honchar Dnipropetrovsk National University, Dnipro, Ukraine
**e-mail: Leonidfil2016@gmail.com*

COMPARATIVE CHARACTERISTICS OF REFLECTION AND TRASMISSION IN MODELS OF WATER FOAM STRUCTURES

A water foam model is presented as same layers with different dielectric and structural characteristics. The proposed model consists of 7 layers; each of them has a low and high level of dielectric permittivity values ε and dielectric loss tangent tgδ. Every layer has its own values of dielectric parameters. The thicknesses of layers of two sizes were taken for calculations: 10 and 15 mm for comparison. The data of experimental investigations of dielectric properties ε and tgδ of water foam specimens were used for calculations in the wide microwave band of 8 – 12 GHz. The reflection and transmission characteristics of electromagnetic waves from foam structures with foaming ratio of layers in the range from 6 to 350 were calculated. The results show the possibility of using water foam structures under conditions of electromagnetic influences for working personnel protection from dangerous electromagnetic waves.

Keywords: microwaves, reflection, transmission, foam, dielectric properties, dispersed media, layered structure, absorption, absorber.

Модель водної піни представлена у вигляді шарів з різними діелектричними та структурними характеристиками. Запропонована модель складається з 7 шарів, кожен з яких має низький і високий рівень значень діелектричної проникності ε і тангенса кута діелектричних втрат tgδ. Кожен шар має свої конкретні значення діелектричних характеристик. Товщини шарів для обчислень було взято двох розмірів: 10 і 15 мм для порівняння. Дані експериментальних досліджень діелектричних властивостей ε і tgδ зразків водної піни використовувалися для розрахунків у широкому діапазоні НВЧ від 8 до 12 ГГц. Характеристики відбиття та пропускання електромагнітних хвиль від пінних структур розраховувалися для різної кратності піни в шарах від 6 до 350. Результати показують можливість використання водних пінистих структур в умовах електромагнітного впливу для захисту робочого персоналу від небезпечних електромагнітних хвиль.

Ключові слова: НВЧ випромінювання, відбиття, проходження, піна, діелектричні властивості, дисперсне середовище, шарувата структура, поглинання, абсорбер.

Модель водной пены представлена в виде слоев с различными диэлектрическими и структурными характеристиками. Предложенная модель состоит из 7 слоев, каждый из которых имеет низкий и высокий уровень значений диэлектрической проницаемости ε и тангенса угла диэлектрических потерь tgδ. Каждый слой имеет свои конкретные значения диэлектрических характеристик. Толщины слоев для расчетов были взяты двух размеров: 10 и 15 мм для сравнения. Данные экспериментальных исследований диэлектрических свойств ε и tgδ образцов водной пены использовалась для расчетов в широком диапазоне частот от 8 до 12 ГГц. Характеристики отражения и пропускания электромагнитных волн от пенных структур рассчитывались для различной кратности пены в слоях от 6 до 350. Результаты показывают возможность использования водных пенистых структур в условиях электромагнитных воздействий для защиты рабочего персонала от опасных электромагнитных волн.

Ключевые слова: СВЧ излучение, отражение, прохождение, пена, диэлектрические свойства, дисперсная среда, слоистая структура, поглощение, абсорбер..

1. Introduction

The propagation of electromagnetic waves in aqueous foam structures is a relevant task of radiophysics. However, due to the complexity of the foam structures, because of – their dynamic character, the problem is still at the stage of theoretical and experimental consideration. This paper is devoted to the study and direct numerical simulation of the boundary problem for investigations of stationary and dynamic foam structures. We consider a model of the foam in the form of laminated dielectric.

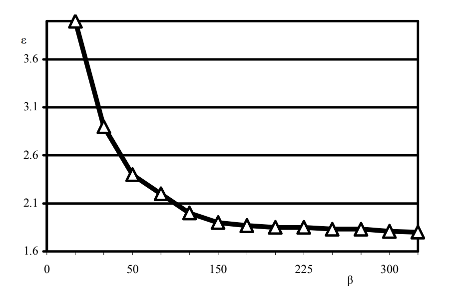
Often the problems in stationary and dynamic foam structures are interconnected. This follows from the fact that at some time moment the structure can be regarded as stationary (in the initial period of its generation and existence) and then a purely dynamic regime may be considered, when the foam structure is at the stage of destruction under the influence of gravitational forces, chemical processes, physical and mechanical causes.

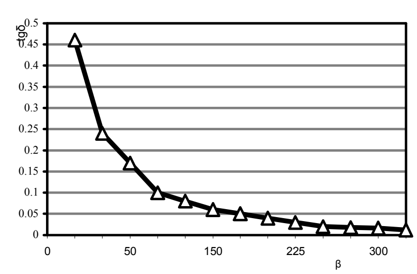
In general, the aqueous foam is a dynamic structure. It would be advisable to create a theoretical model, which would allow solving the direct problem of electromagnetic wave propagation, both in the dynamic and stationary formulations. But it is a very difficult task, so we first simplify the problem and take in account the stationary case with the relative stability of its structure in time and permanence of its geometric and dielectric parameters.

Papers about foam investigations were well known for remote sensing in 1960-1990 [1]. In 2003-2006 we investigated liquid foam structures in open space [2, 3]. In 2012-2014 we studied foam in solid state [5 – 8].This paper presents calculations of the reflection and transmission characteristics of electromagnetic waves. They were made through Finite Element Method. The calculations were performed in the range of 8 – 12 GHz. They were based both on geometrical parameters of layers and their dielectric characteristics. The geometric dimensions, dielectric permittivity, and dielectric loss tangent were previously obtained from results of the study of quasi-dynamic water foams [4].

2. Data for calculation

The basis for calculations using the Finite Element Method is the way of finding the data, particularly values of dielectric permittivity and dielectric loss tangent as well as the geometric size of every layer.





(a) **(b)**

Fig. 1. Dielectric permittivity ε dependence on foaming ratio β (a).
Loss tangent tgδ dependence on foaming ratio β (b).

Necessary data and characteristics such as dielectric losses of foam samples for different foaming ratio and the dependence of the dielectric parameters that are indicated in Fig. 1a and 1b were taken from the Ref. [4]. Also from this paper we found that the foaming ratio was in range from 6 to 350.

Information from Fig. 1a and 1b corresponds to the characteristics of electromagnetic waves in the range of 8 – 12 GHz.

3. Calculations

The information taken for every layer was very useful for computations. The layers have different values of dielectric characteristics (given in Table 1) in the samples of chosen structure. The range of foaming varies from 6 to 350 that is a very large range.

Calculations of the reflection and transmission characteristics of electromagnetic waves were fulfilled by means of the Finite Element Method. The point of the method is that the space, in which the electromagnetic waves propagate, is divided into elementary volume elements, having the form of tetrahedrons.

Table 1

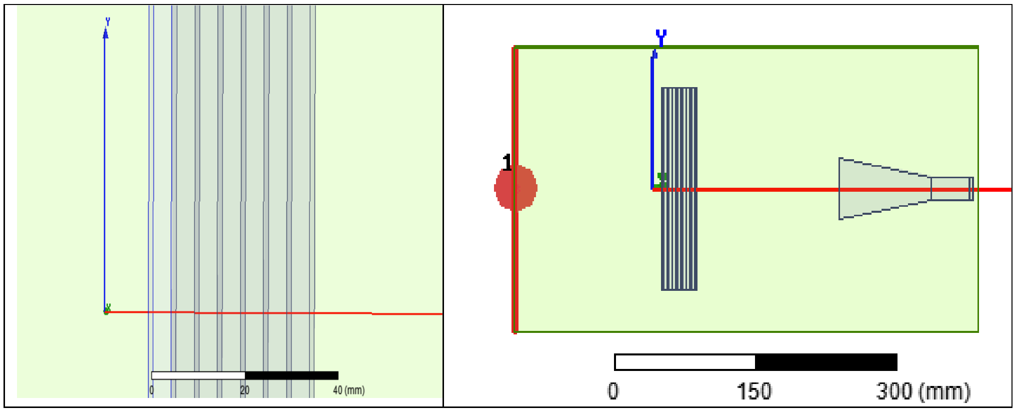
Dielectric characteristics of layers

Layer (No.)	*Value of dielectric permittivity*	*Value of dielectric loss*	*Thickness of layers*	
			1 version (mm)	*2 version (mm)*
1	2	0.3	10	15
2	2.3	0.35	10	15
3	2.65	0.42	10	15
4	3	0.48	10	15
5	3.3	0.55	10	15
6	3.62	0.62	10	15
7	4	0.63	10	15

As it seen from Fig. 2a, the layered structure consists of seven layers of the same thickness. Calculations were made for two different versions (thicknesses). Every layer thickness is plate and every layer has a position that is very close to neighboring layers, without any gaps. So, the total thickness of the structure was 70 mm (1 version) and 105 mm (2 version).

We composed models with different thicknesses according to Table 1. In this case we have got a distributed profile of dielectric permittivity values and dielectric loss tangent in the structure layers like it is proposed in Table 1 and usually corresponds to measurements in real water foams.

Here the upper layer (Number 1) has a foaming ratio of about 350 when the bottom layer (Number 7) has it of about 6. In the appropriate way, for layer number 1 the dielectric permittivity ε has a value 2 and the dielectric loss tangent $tg\delta$ has a value 0.3, while for the layer No. 7 dielectric permittivity value ε has a value 4 and dielectric loss tangent $tg\delta$ has a value 0.63 – that is 2 times higher than for the 1st layer. Dielectric permittivity ε increasing from layer to layer is about 0.3 – 0.4 and dielectric loss tangent $tg\delta$ increasing from layer to layer is in the limits of 0.01 – 0.06.



(a) **(b)**

Fig. 2. Foam model in the form of laminated dielectric of 7 layers (a).

Scheme of measurements (b).

In Fig. 2b the measurement scheme is presented. It consists of a section of rectangular waveguide with cross-section 23×10 mm in size, horn antenna, layer structure, and two ports. In the case of rectangular waveguide section, horn antenna, layer structure, and two ports are situated on the axis Z symmetrically.

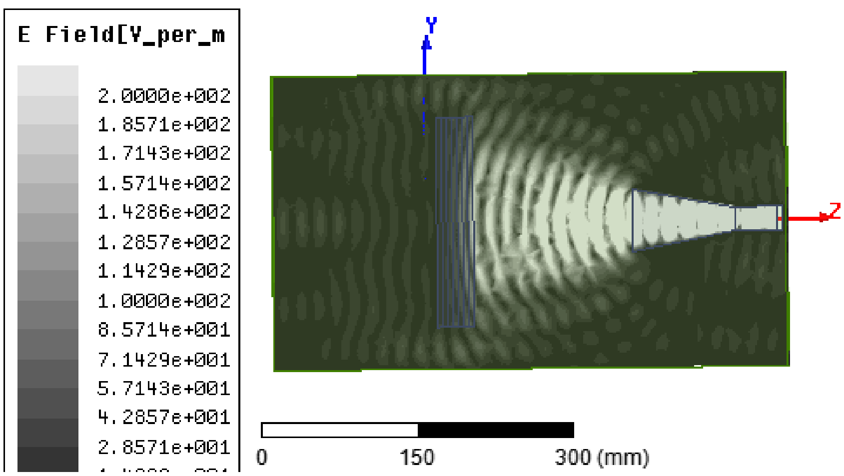


Fig. 3. Interference image of reflected and transmitted waves (E –field, plane YZ).

The first port is situated inside the rectangular waveguide section, on the end wall, and is used for the generation of electromagnetic waves. It is also used for receiving the reflected electromagnetic waves. Values of reflected and radiated electromagnetic waves are used for calculating the S11 – coefficient of reflection.

The antenna was used with the aperture of 70×70 mm. It was installed in front of the structure to be investigated at a distance of 150 mm from the aperture of antenna to the front plate (first layer) of the structure. The receiving port was installed at a distance of 150 mm after the last plate (7^{th} layer) of the laminated dielectric.

In Fig. 3 a picture of interference (E –field, plane YZ) is presented where bright points reflect high amplitudes and dark points reflect low amplitudes of the field.

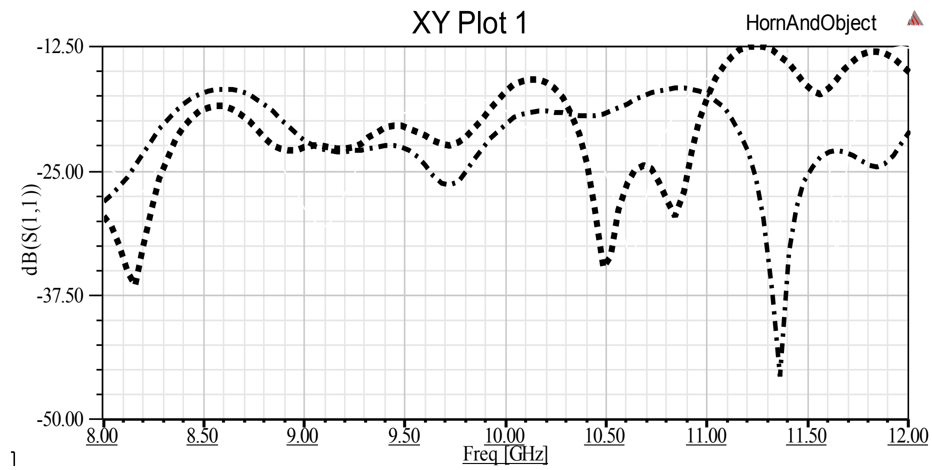


Fig. 4. Characteristics of reflection for foam structure models with thicknesses 10 mm (dot line) and 15 mm (dash-dot line).

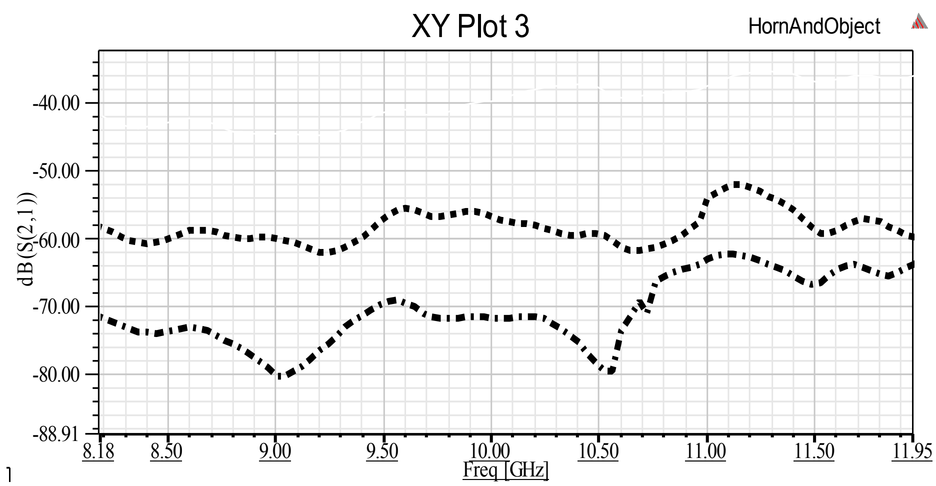


Fig. 5. Characteristics of transmission for foam structure models with thicknesses 10 mm (dot line) and 15 mm (dash-dot line).

4. Analysis of results. Conclusions

In the paper a comparative research of the reflection characteristics S11 and characteristics of transmission S21 of electromagnetic waves is presented for different layer thicknesses.

The number of partitions makes the value of 46102 tetrahedra. Calculations were performed in 100 frequency points, one calculation after another with distance in 0.04 GHz. It is possible to obtain smooth curves.

The work was fulfilled for the values of layer thickness of 10 and 15 mm. From Fig. 4 it is easy to see that reflection curves have the same resonances as a result of wave interference and the reflection value S11 is in the range from about −12 to −34 dB. It means that on the average reflected wave amplitudes are 100 times less than amplitudes of an incident wave. There is practically a very small dependence of reflection on layer thickness.

For models under consideration the calculated curves of transmission are very dependent from thickness of layers. The transmission value S21 is very small, it is within the limits of about from −52 to −80 dB. This shows a great level of absorption of electromagnetic waves.

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