671. Study of the process of interaction between low-frequency ultrasound and biological tissue phantoms

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Abstract. This paper presents the results of a series of experimental studies on the impact of low-frequency ultrasound on biological tissue phantoms, acoustic pressure on the motion of particles in an acoustic field generated by annular waveguide. Experiments have demonstrated that when vibrations with a frequency corresponding to its natural frequency of bending vibrations are induced in the annular waveguide, micropowder particles form arranged bulk structures on the substrate. Analysis of results on the behavior of micropowder particles in the ring insonation area revealed that frequency variations of ultrasonic vibrations lead to variations in spatial distribution of acoustic pressure inside the ring. The thermal effect of low-frequency ultrasound from annular waveguide on biological tissue phantoms has been studied. It was established that the annular waveguide enables heating of fluid when it has no direct contact with the media, thereby demonstrating its applicability for non-contact treatment of tumors.

Keywords: ultrasound, biological tissue phantoms, acoustic field, low-frequency vibrations.

Introduction

Malignant laryngeal neoplasms rank first in frequency among head and neck tumors. Laryngeal surgery may lead to multiple complications as well as patient disability due to the loss of speaking ability. Besides, mucosa of vocal folds is thin and easy to damage, neoplasms may bleed when touched, but the contact of a tool with the tumor may lead to metastases. Therefore, non-contact treatment methods are of high importance in the case of tumors of such localization.

The paper [1] shows that the use of ultrasound with frequency of 22-23 kHz and strength of 2.0 W/cm^2 and 2.5 W/cm^2 as a modifier allows to increase the efficiency of radiation when treating malignant skin neoplasms. Low-frequency ultrasound was introduced into a biological tissue by enveloping the tumor with special annular waveguides. [3-5]

To experimentally confirm the possibility of non-contact impact to biological tissues using annular waveguides, we studied the impact of acoustic pressure (generated in the ring during resonances) on changes in biological tissue phantoms temperature, distribution of the radiation pressure on ring axes at different distances and on the behavior of micropowder particles in the insonation area.

Experimental research

The research was conducted using an acoustic system consisting of an ultrasonic concentrator 1, a wire waveguide 2 and a ring 3 (Fig. 1).

Analysis of the results of the studies of the behavior of micropowder particles in the insonation area demonstrated that frequency variations of ultrasonic vibrations lead to variations in spatial distribution of acoustic pressure inside the ring.

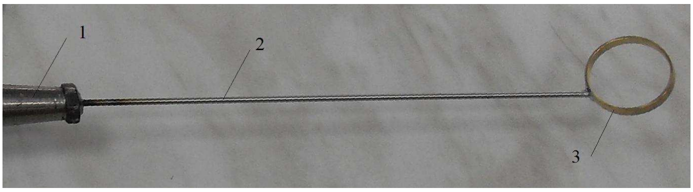

Fig. 1. Waveguide with the annular working section

a) b) c)

Fig. 2. Direction of the movement of micropowder particles in an acoustic field when frequency changes

Thus, Fig. 2 illustrates a waveguide with a ring of 25 mm in diameter with a tangential input of vibrations at an angle of 0°. Protacryl micropowder particles are placed inside the annual element, located under the substrate surface at a distance of 0.5-1 mm. At frequency of 32.7 kHz particles move into the ring from the periphery and form multiple monolayers in the form of vertical walls (Fig. 2a), at frequency of 32.8 kHz – particles not located in nodal planes move out of the ring (Fig. 2b), but at frequency of 32.9 kHz, which corresponds to the resonance frequency, they group in the middle of the ring and perform a circular movement around the axis of the annular element (Fig. 2c).

The study of the thermal effect of low-frequency ultrasound from annular waveguide was conducted using 0.9% aqueous solution of sodium chloride (saline) and distilled water.

Fig. 3 provides the dependence of saline temperature on ultrasound effect time. The presented dependence demonstrates that at constant impact of ultrasound, the temperature of saline rises on average by 1.9° at strength of ultrasound 2.5 W/cm^2 and tangential input of vibrations at an angle of 0°.

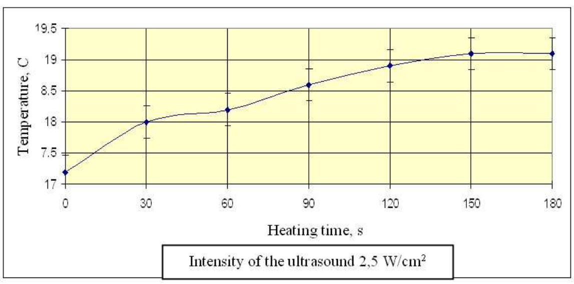

Fig. 3. Dependence of saline temperature on heating time

It is evident that the higher the ultrasound strength, the higher the rise of temperature of the insonated phantom. We can respectively assume that other processes induced by the ultrasonic effect are more intense.

It should be noted that in practice the temperature of biological tissues from the impact of ultrasound is lower than in the experiment on phantoms, because, firstly, they differ by their composition from saline, secondly, blood and lymph constantly circulate in tissues. The paper [1] shows that in biological tissues of animals insonated with annular waveguides, the tissue temperature rises by 0.9° in 3 minutes at vibration strength of 1.5 W/cm^2. In our case, the power of 2.5 W/cm^2 gave us the maximum heating by 1.9° in 3 minutes.

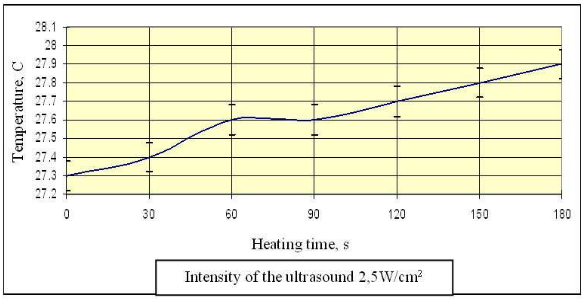

Fig. 4. Dependence of saline temperature on time at non-contact heating with an annular waveguide

When studying possibilities of non-contact heating of biological tissues, we employed a phantom which constituted a package made of latex filled with 3.5 ml of 0.9% of aqueous solution of sodium chloride (saline) with a platinum thermal resistor placed inside. Research results are provided in Fig. 4. It was demonstrated that annular waveguide allows to heat fluid when it has no direct contact with the media, and therefore it may be used for non-contact treatment of tumors. The phantom heated by 0.6° in 3 minutes at ultrasound strength of 2.5 W/cm^2.

Fig. 5 presents the dependence of qualitative variations in radiation pressure on the ring axis. The research revealed that the maximum pressure is observed in the focus on the ring axis, and the shielding of the back focus leads to the double or triple increase in the amplitude of radiation pressure on the ring axis (Fig. 6). It enables contactless insonation of biological tissue.

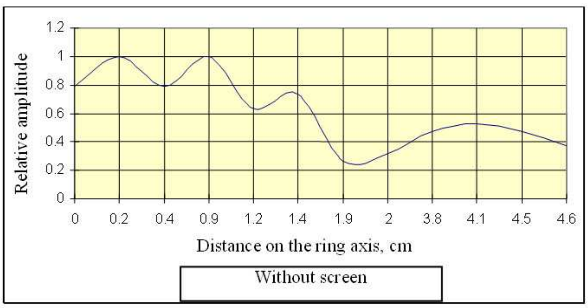

Fig. 5. Radiation pressure on the ring axis

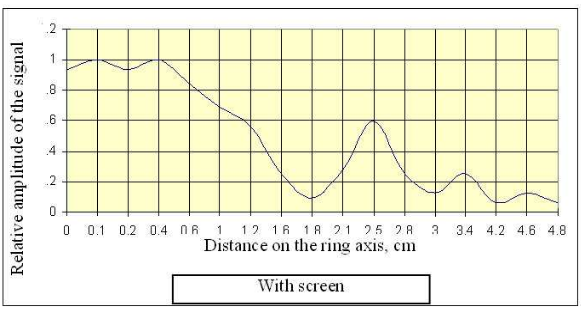

Fig. 6. Radiation pressure on the ring axis with shielding

Conclusions

1. It has been experimentally confirmed that the acoustic field induced by the annular waveguide at its resonance may be applied for non-contact impact on biological tissue.
2. Non-contact methods of adjuvant therapy of tumors increase the efficiency of beam therapy and are safer and less traumatic for patients compared to traditional treatment of malignant neoplasms.

Acknowledgements

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