10. Problem №13: Sound

10.1. Solution of Bulgaria

Problem №13: Sound

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The Problem

***Measure the speed of sound in liquids using light*.**

A well-known method exists, using which one could measure the speed of sound in liquids, using light. If inside a rectangular vessel one creates a flat ultrasonic standing wave, the denser areas of the liquid will form a phase diffraction grid. A thin laser ray, traveling through the vessel will diffract and from the angle of diversion of the first maximum the length of the standing wave could be calculated. That is how the speed of ultrasonic sound is measured. However, there are difficulties around creating a standing ultrasonic sound wave with a length of 0,1-0,5 mm containing 10^2 knots. One of these is the great fade of the ultrasonic wave inside liquids. All of our efforts to create such a phase diffraction grid failed.

Idea

The idea that we managed to realize was to use a sound wave with a greater length and a Michelson interferometer...

If inside a square vessel, filled with liquid (water) we put a M. Interferometer, so that one of its arms is in the same direction, in which the wave travels, and the other – perpendicular to it, a difference in the optical paths will occur in the interferometer. That will be registered by the sensitive device, as a change in the interference pattern.

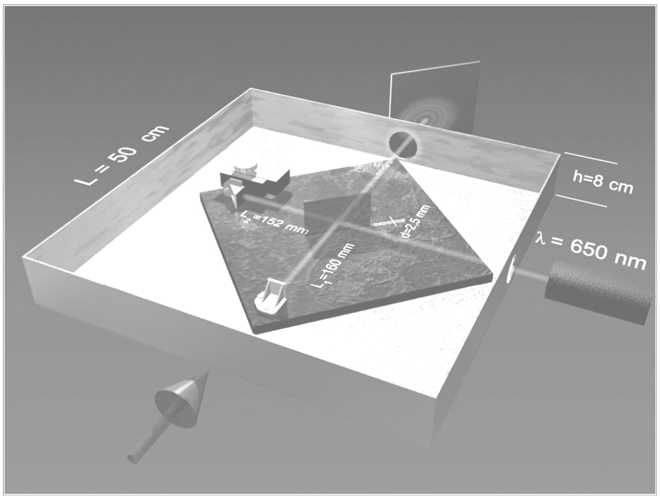
Provided that we manage to create a standing wave within the vessel, with a half-length equal to the vessel's side, that will be the mode with the lowest frequency, for which we will be able to register a change in the interference pattern. Such a change would appear due to two reasons:

1.A difference will occur in the optical paths of the rays in the two arms of the interferometer, due to the difference in amplitudes of deviation of the refraction coefficient of the liquid. The deviation in the position of the maxima will lead to a decrease of the contrast of the image.

2. a difference in the optical paths could occur due to vibrations of the mirrors. The result will be the same.

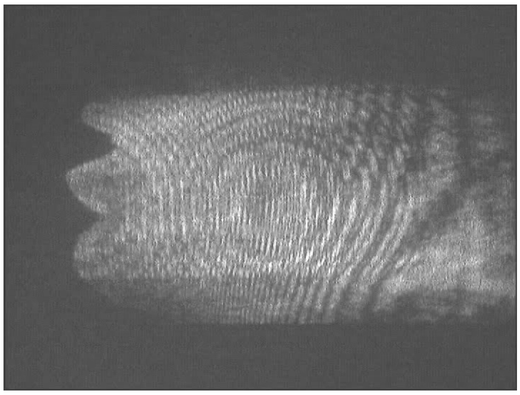
Experimental stage

The square vessel, in which we created the standing wave by applying vibrations to one of its sides, has the following measurements 0,5 x 0,5 x 0,08 м. Wholes have been made in two of the sides of the vessel and they are closed with evenly parallel glass pieces, so that the ray may enter and exit the vessel. фиг.1



The Michaelson interferometer consists of two mirrors, placed over a ceramic tile with measurements 30 x 30 cm, so that the two arms are respectively 152 мм and 160 мм. The difference in length of the arms is needed, as one of the rays passes through the semitransparent piece trice, unlike the other. One of the mirrors is placed on the micrometric screw, so that the interferometer could be set. Using the optic system the ray is transformed into a divergent one, so that the interferential image consists of concentric circles – maxima and minimums. This makes the interferential pattern different from the additionally appearing interferential patterns. On фиг1.one can see the side that is given vibrations, marked with a pointer, so that a standing wave could be formed. The real stage, with the interferometer dipped in water is seen on фиг. 2, and on фиг.3 – the interferential pattern.

Фиг.2



Фиг.3

Assessment of the interferometers accuracy

The condition for seeing a maximum using the Michaelson interferometer is that the difference in optical paths of the two rays, 1 and 2 is a whole number of half lengths of the wave.

$$L_1 - L_2 = n_1.l_1 - n_2.l_2 = 2.k.\frac{\lambda}{2} \qquad k = 1, 2, 3, \ldots, n$$

Let us now presume that the optical length of one of the arms changes (for instance L_1). If that change is one with λ/2, then every maximum with number k will move to the position of a maximum number k+1 or k-1. If that change is 1/10 λ/2 the human eye will see it. If the change is with a larger frequency the interferential structure will appear blurred, and for larger amplitudes the pattern will completely disappear.

1. The deviation in optical path of one ray is a result of the deviation of the refraction coefficient.

$$\Delta L_1 = n_1.l_1 - n_2.l_1 = \frac{\lambda}{2} \quad ,$$

Maximum number k is moved to the place of maximum number k+1-st.

$$(n_2 - n_1).l_1 = \frac{\lambda}{2} \quad \Rightarrow \quad \Delta n = \frac{\lambda}{2.l_1}$$

For values of λ and l_1 respectively:

$$l_1 = 0{,}160\,m$$

$$\lambda = 6{,}5.10^{-7}\,m$$

The accuracy of the interferometer regarding the refraction coefficient is:

$$\Delta n = 2{,}031.10^{-6}$$

When we visually follow the change, that accuracy is one order higher.

2. The change in optical path length of one of the rays is a result of the change in distance (vibrations of the respective mirror).

$$n.l_1' - n.l_1'' = n.\Delta l_1 = \frac{\lambda}{2} \qquad \Rightarrow \qquad \Delta l_1 = \frac{\lambda}{2.n}$$

For values of $n = 1{,}33$ и $\lambda = 6{,}5.10^{-7}\ m$

$$\Delta l_1 = 2{,}44.10^{-7} m$$

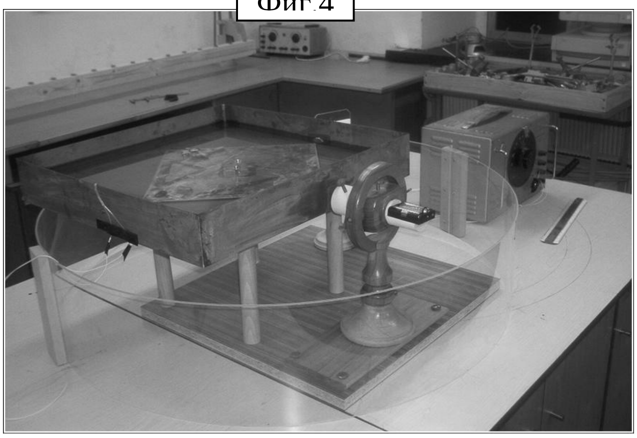
Here as well, visually following the change increases the accuracy with one order.

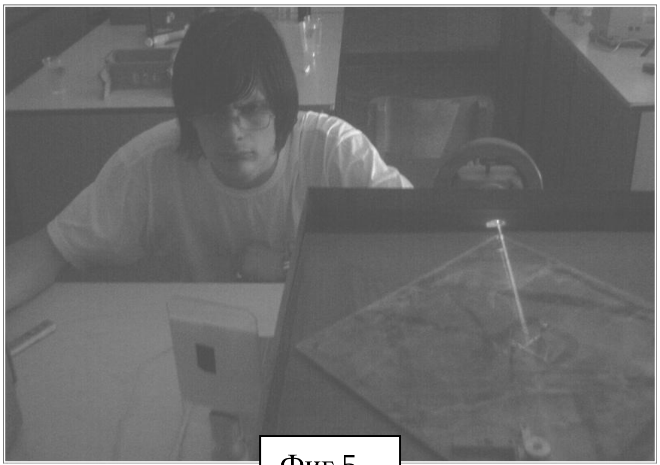
We expected the interferometer's accuracy to be good enough to register the difference in states of the media – either a standing wave occurs or not.

Experiment

On фиг.4 one can see the whole experimental stage. In the left part of the photo one can see the wires, connected to the loudspeaker, using which we set vibrations to the side of the vessel. The first part of the experiment consists of defining the resonance frequencies of the stage with no liquid being present in the vessel. When we hit the resonance frequencies of the sides, bottom of the vessel, ceramic tile, the strongest blur of the image must occur. For greater precision when we carry out the experiment we record the sound, so that when we gat a blur of the pattern we could with the help of some software determine very accurately the frequency. The results were the following frequencies.

Фиг.4





Фиг.5

$$\nu_1 = 570 \ Hz$$
$$\nu_2 = 860 \ Hz$$
$$\nu_3 = 1139 \ Hz$$

After filling the vessel with water the same frequencies, at which the described effect occurs were found.

$$\nu_1 = 551 \ Hz$$
$$\nu_2 = 844 \ Hz$$
$$\nu_3 = 1045 \ Hz$$
$$\nu_4 = 1593 \ Hz$$

The first three resonance frequencies are shifted, due to the loss of energy, caused by the presence of liquid. The appearance of a fourth resonance frequency we explain with the deviation in refraction coefficient or vibrations of the mirrors when a standing wave occurs inside the vessel. This should be the mode with the lowest frequency.

$$\frac{\lambda}{2} = l \quad ,$$

where l is the length of the vessel's side - 50 cm. From the well-known equation $c = \lambda . \nu$

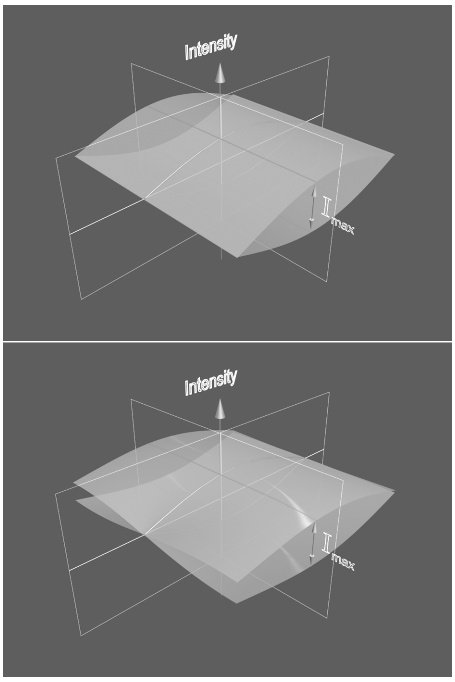
we define the speed of sound in water

$$c = 1593 \ m/s.$$

A difference of *111 m/s between the speed we defined and the well-known one,* however, exists. The explanation, in our opinion is the following.

When calculating the speed of sound in liquids we presupposed that the sound wave propagating through the vessel is a flat one. From that follows the simple standing wave equation as well $l = \lambda/2$

The wave, propagating inside the vessel, however, is not flat but spherical (фиг.6). The standing spherical condition is not so simple. Our proposal is that the error of 111 m/s occurs due to that difference in wave types.



Фиг 6

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1. Персел.Е., Берклиевский курс физики, , т.II, Наука, 1972г.
2.Савельев, И., Курс общей физики, Наука 1972г.