INVESTIGATING THE SOUND PRODUCED BY HITTING A METAL ROD (IYPT 2010 PROBLRM NO.13)

Zahra Karimi
Dept. chemical eng,Iran,Sharif university of technology.

Abstract: Working with the sound waves while there are several types of motions and several patterns can be a complicated task. This paper contains the results of investigating the sound waves caused by hitting metal rods which are held from one point within their length. In this case there are many different patterns which are caused by longitudinal and transverse waves propagating within the rods.

Keywords:rod,longitudinal waves,transverse waves

Introduction: many of the interesting effects and phenomena in physics are caused by various behaviors of the waves e.g. sound but unfortunately high school students don't have enough experimental experiences with sound waves. One of the goals of this paper is to figure out different patterns of sound waves which can propagate within a metallic rod both in theory and experiments (the focus is on standing waves).
It's been proved that both longitudinal and transverse waves can propagate in solids. In the case of cylindrical metal rod which should be held at a certain position within its length and be hit, for finding the right patterns of propagation paying attention to both holding point and hitting type is necessary.

Hypotheses: Holding point can be considered as a node because approximately there is no motion at this point, this node is really critical in understanding the accurate pattern of longitudinal and transverse waves.
A metallic rod is quite similar to a tube which is open from both ends so when it comes to longitudinal motion only the fundamental frequency or harmonics which have the same place of nodes with the holding point can be observed. This means that the longitudinal wave can only be produced by holding the rod at even multiples of the length (1/2L.1/4L.1/6L,…).(figure 1)

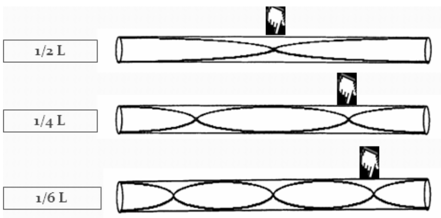


Figure 1

Note that the place of node affects the propagation of the transverse wave as well as longitudinal wave but the fundamental frequency and harmonics of transverse wave are not as simple as longitudinal wave but the second harmonic of the transverse motion and fundamental of longitudinal motion both have nodes at center.
There are two general types of hitting the rod one is striking it at the end (figure 2) and the other is hitting it downward (figure 3).

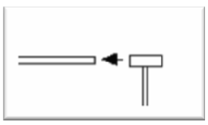
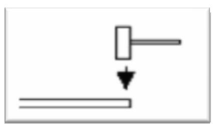


Figure2

Figure3


when the rod is been stroke at the end there will be a longitudinal wave (if it's been hold at the points mentioned above e.g. 1/2L,1/4L,…) but if it's been hit downward, both longitudinal and transverse motion can be observed. To go through the details, paying attention to the vibration which is caused by each type of hitting and the direction of propagation of the wave (sound) can be helpful. When the rod is stroke at the end there will be a horizontal vibration at the end while the wave is propagating horizontally within the rod's length as well, this situation is the description for a longitudinal motion (as it is mentioned above, the place of holding is important too), but when the rod is been hit downward both vertical and horizontal vibrations can be produced and these vibrations cause waves which are propagating horizontally , in this case both longitudinal and transverse waves can be produced(again the place of holding is important) .

Experiments: For going through the details of the wave patterns, proving the hypotheses and investigating the effect of different parameters on the sound caused by hitting the rod, experimental observation is indispensable.
Parameters bellow are those which their effect on propagation of sound waves in the rod will be explained in the experiments.
-length of the rods**-**material of the rods**-**place of holding**-**type of hitting-place of hitting
For understanding the effect of each parameter on the sound waves having the frequency and intensity of the waves and their diagrams is essential, the best way to measure these two parameters and achieve to waves' diagrams is doing a Fourier transform on the sound caused by hitting the rods.

Experimental setup:
The setup which experiments were done with contains a microphone which is placed at a constant distance from the rod (in order to record the sound), a hammer for hitting the rod and a rod (it's been held tight from one point within its length).(figure4) &(figure5)

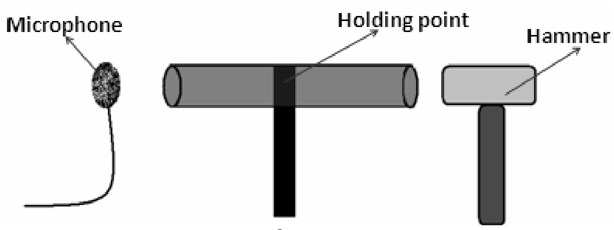


Figure4

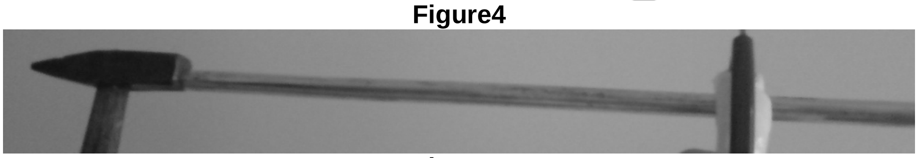


Figure5

The process of each experiment:1-hitting the rod 2-recording the sound with a microphone (Neumann U 87 Ai capable of recording 16 to 18000 Hz) attached to a computer 3-doing the Fourier transform on the sound with a software(Cool Edit Pro 2.0) 4-analayzing the diagram(amplitude verses frequency)

-Effect of the length and holding position

Harmonic longitudinal motion: In this part the experiments were done with aluminum and steel rods in different lengths and each of them were hold from three different positions (center, 1/4 of the length,1/6 of the length) and been hit, in each case the longitudinal frequency is measured from the diagram of the sound recorded from the experiment (e.g. figure 6)

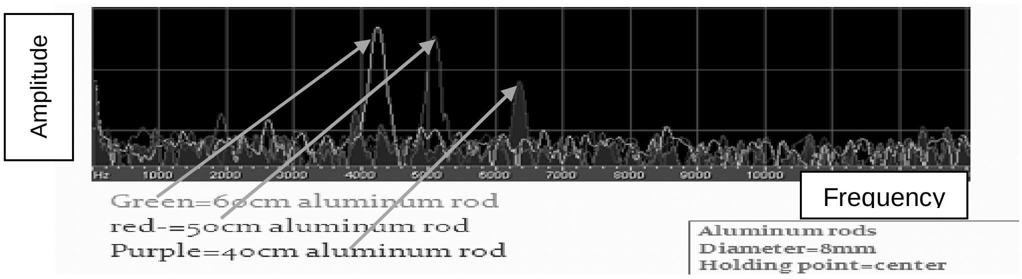


Figure6

For doing a comparison between the numbers came from the experiments and the theory, expected frequency for each rod has been measured due to its holding position and material, there is an example of measurements done for achieving to the expected number of frequencies:

L=60cm a=12mm v=4963.3m/s * Holding point=1/2 L .1

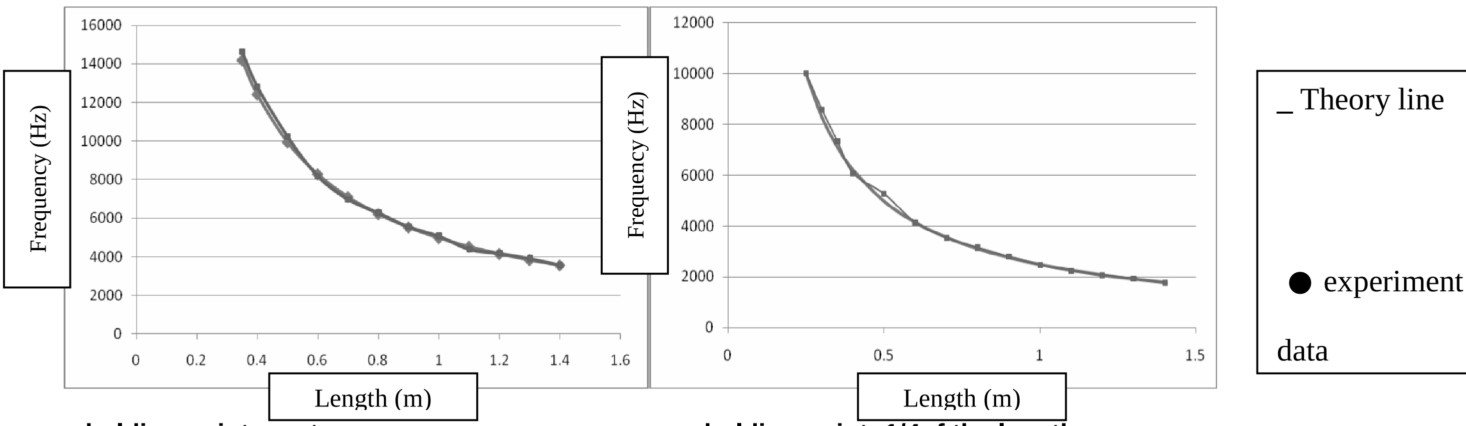
$$f_n = n\left(\frac{V}{2L}\right) \quad n = 1, 2, 3...$$

$$f = \frac{v}{\lambda}$$

$$\lambda = 2L$$

$$f_L = \frac{4963.3}{1.2} = 4136.08\,Hz$$

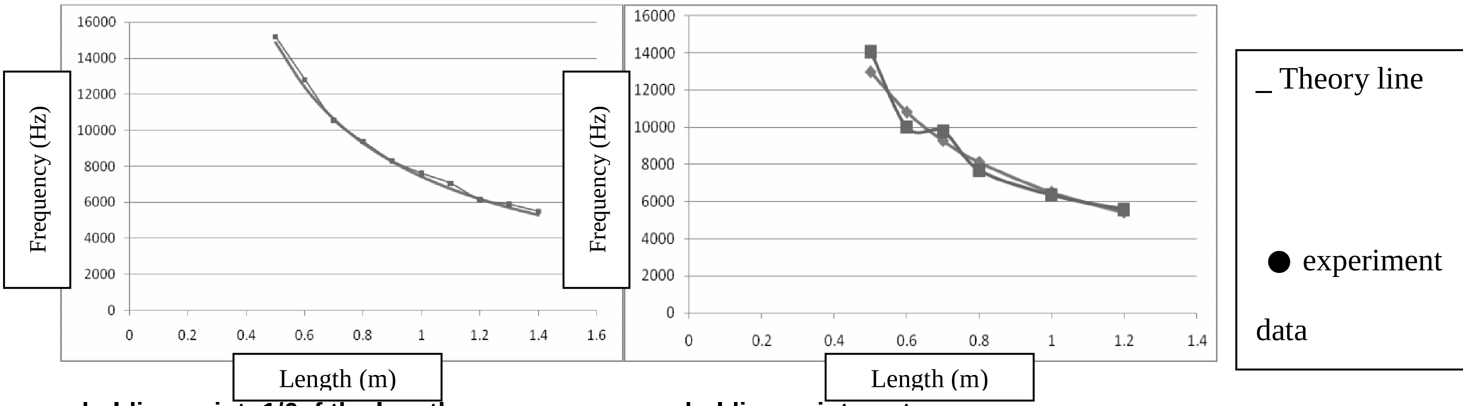
To visualize these comparisons there are graphs which were drawn by the numbers came from experiments and the numbers measured by the theory.(vertical axis is frequency(Hz) and the horizontal axis is length of the rods(meter).



holding point: center
material: aluminum diameter:12mm

holding point: 1/4of the length
material: aluminum diameter:12mm

*the speed of the sound in aluminum is measurable by knowing its young modulas and density following the formula: $v = \sqrt{\frac{Y}{\rho}}$



holding point: 1/6of the length
material: aluminum diameter:12mm

holding point:center
material: aluminum diameter:12mm

As it is obvious in each case theory line fits the experiment data, but there are some other longitudinal waves which can be observed in the diagrams of the sounds, these longitudinal waves appear in the form of a fundamental frequency and its odd harmonics (exactly like a tube which is closed from one end).

e.g. Aluminum rod - length=140cm- diameter=12mm - holding point center

These frequencies can be observed in the diagram

1756 Hz-5297Hz-8828Hz-12360Hz

5297=1756*3.001 8828=1756*5.001 12360=1756*7.002

From the data above it can be conclude that 1756Hz frequency is the fundamental and other frequencies are the odd harmonics. From the formula of longitudinal waves the length of the rod which is producing these frequencies can be measured.

$$f = \frac{v}{\lambda}$$

$$\lambda = 4L$$

$$f = 1756Hz$$

$$1756 \times 4L = 4963.3$$

$$L = 0.70m$$

For the example above 70cm is exactly the distance between the holding point and hitting position, this means that the part of the rod which is between the holding point and hitting position is acting like a tube which is closed from one end.

These phenomenon was repeated for other places of holding (1/4 length and 1/6 length) as well.

e.g. Aluminum rod - length=140cm- diameter=12mm - holding point=1/4 of length

These frequencies can be observed in the diagram

3576 Hz-10720Hz-17522Hz

10720=3576*2.99 17522=3576*4.9

And again measurements show: ⟶

$$f = \frac{v}{\lambda}$$

$$\lambda = 4L$$

$$f = 3576Hz$$

$$3576 \times 4L = 4963.3$$

$$L = 0.346m$$

0.35≈This number is approximately equal to ¼ of the length: 0.346

These waves can be observed in the rods with shorter or longer lengths as well.

Harmonic transverse motion: unlike the longitudinal harmonics detecting the transverse harmonics is not easy, this is because of quick damping and small frequency of these waves, but still in some cases these waves are detectable.
For example in steel rod (length=0.5m, radius=1mm) if it is held from center the second and forth harmonics which have same nodal positions are expected to be produced.[1]
Frequencies of these waves are measured as bellow:[1,2]
v=6100 m/s (v=velocity K=radius of gyration for cross section L=length)

$$f1T = 3.5607 \frac{K}{L^2} V \quad f4T = 8.933\, f1T$$

$$f1T = 43.44\ Hz \quad f2T = 388\ Hz$$

The frequency detected in the experiments for this case was 405 Hz

Transverse and longitudinal waves
-type of hitting
Type of hitting won't cause any change in longitudinal motion but it will affect the existence of the transverse motion.(figure 7)&(figure8)

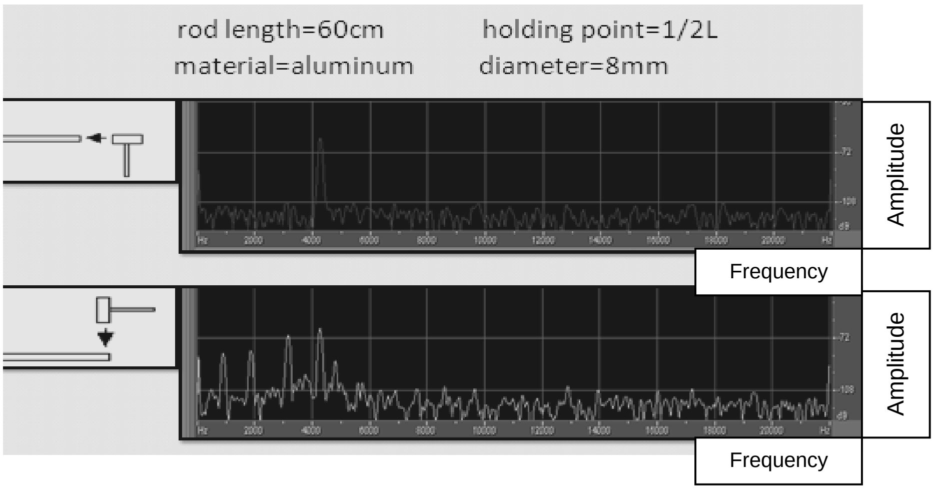


Figure 7

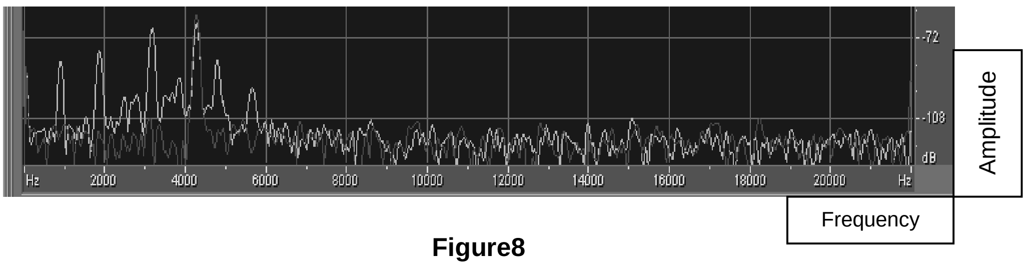
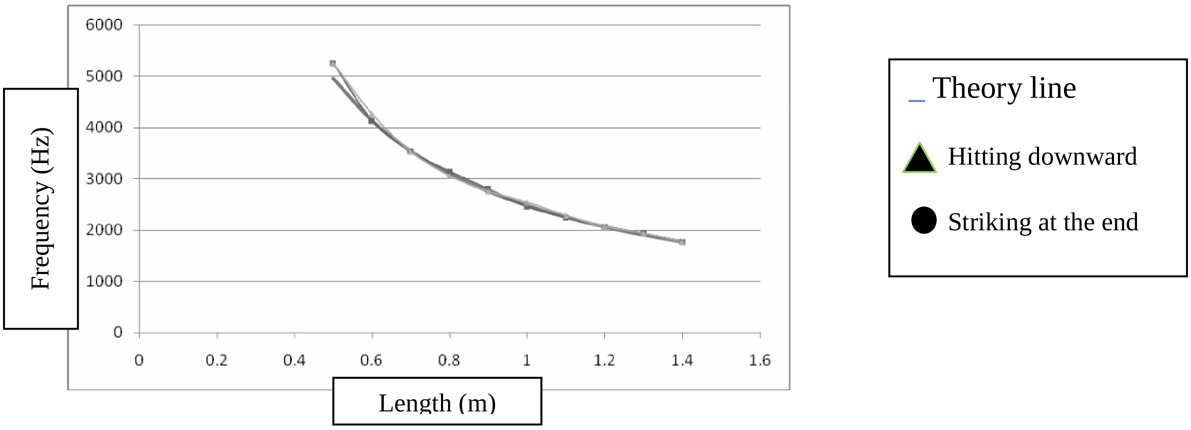


Figure8
The longitudinal fundamental in both cases=4306Hz

Note that by hitting the rods downward some transverse waves will occur but they will damp quickly and they are not the expected transverse harmonics unless the rod is held from a transverse harmonic nodal point, the term transverse motion is referred to these waves due to their structure but they shouldn't be misunderstood with harmonic transverse motion.

For going through the details about this fact that longitudinal waves won't change by changing the type of the hitting again using a graph can be helpful.

Holding point: center   material: aluminum diameter: 12mm



For longitudinal waves these three data series fit on each other, this means that the longitudinal motion is independent of hitting type.

Effect of hitting place: although both transverse and longitudinal motions in the rod are dependent to the holding place (which is considered as a node) but both of this waves are independent of place of hitting.(figure9)

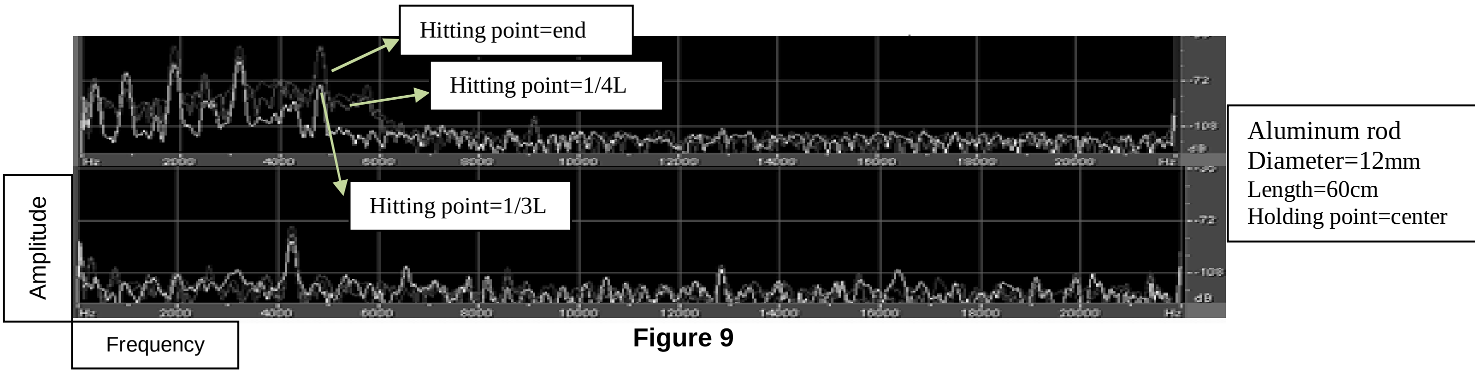


Figure 9

Figure 10 shows the diagrams of the sound caused by hitting the same rod at different positions in different colors. Frame one is in the first second after hitting and frame two is milliseconds later, in frame two only the longitudinal motion can be observed, this is because of the longer sustainability of the longitudinal waves in compare to transverse waves due to their less energy loss.

Effect of diameter: although the longitudinal waves are independent to the rod's diameter but transverse motion can change by changing the rod diameter, this is simply because of the structure of transverse waves.

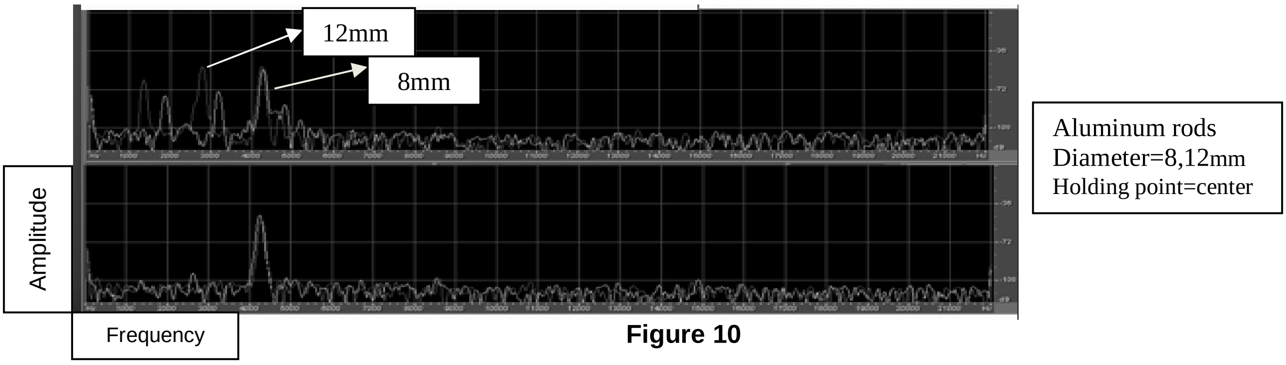


Figure 10

In the first frame of figure10 it is observable that two diagrams (belonging to two rods with different diameters but same materials) don't fit on each other in the first two frequencies but they fit on each other in the third frequency (third frequencies are the longitudinal frequencies due to the measurements and their longer sustainability).in frame two which shows the situation of the waves a few milliseconds after the first frame (after the disappearing of the transverse motion) it is clearly obvious that the longitudinal waves of the both rods fit on each other and have the same frequency.

Summary of the results:

-Both longitudinal and transverse motion can occur in the rods.
-Hitting the rod downward in any place within its length will cause a transverse motion.
-There is a node at holding point.
-Standing longitudinal waves can only occur when the holding point is at an even multiple of the length (measurable nodes)
-The place of hitting won't affect the longitudinal waves.
-The transverse waves are dependent to the rod diameter.
-Rod material won't change the behavior of the transverse and longitudinal waves propagating in it.
-Some of the longitudinal waves in the rod are produced by certain parts of the length not all of it.

References

[1]Thomas D.Rossing and Daniel A. Russell,Laboratory observation of elastic waves, Department of physics,Northern Illinois University ,1-8,1990
[2] Professor Paul Doherty, Ringing aluminum rods,2-8. 1997
[3]Professor Steven Errede ,The physics of longitudinally vibrating 'singing'' metal rod,university of Illinois in Urban,2-10.2002
[4] Arbor Scientific,Singing rods,2-3.2001
[5] David R.Lapp,Harmonics in an aluminum rod,1-2,1997