Development of a Standing Wave Prototype for Meaningful Learning of Engineering Physics

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Abstract - *Standing waves remain confined in one space (string, air tube, membrane). The amplitude of the oscillation for each point depends on its position, the frequency is the same for everyone and coincides with that of the interfering waves. It has non-vibrating points (nodes), which remain stationary, while others (bellies or antinodes) do so with a maximum vibration amplitude, equal to twice that of the interfering waves, and with a maximum energy. The standing wave name comes from the apparent immobility of the nodes. The distance between two consecutive nodes or two antinodes is half a wavelength.*

For a string, there are only certain frequencies at which standing waves are produced which are called resonance frequencies. The lowest is called the fundamental frequency, and the rest are integer multiples of it (double, triple, among others).

The lack of prototypes or didactic material in the physics for engineering subject (a subject that falls within the 2017 course of study at the Technological University of Tlaxcala at the engineering level) that allows us to apply the theory with the practice of these topics to make significant learning motivated the teacher responsible for the subject and students of the seventh semester of engineering in industrial maintenance (IMI) to design and build a didactic prototype of standing waves to be able to verify and apply their mathematical equations in the prototype.

Key Words: *Prototype, design, construction, standing waves, meaningful learning.*

1. INTRODUCTION

In the teaching of physics, the laboratory plays a role very important within meaningful learning like fundamental element of student interaction with laws and phenomena [1]. The study of science and in particular Physics traditionally has had a certain dislike for students when learning mechanically and may be the cause that the opportunity to fix concepts and reasoning has not been consolidated logical abstract [2].

Traditionally, teaching has been guided by practices in which "I teach and you memorize", or "I speak and you listen". Today, the new educational paradigm prioritizes the need for students to be trained under a learning framework where the student works with what they already know, with their cognitive structure. This means that the contents to be managed must respond precisely to the student's experience, to the previous and relevant knowledge that allows him to link the new information with the one he already has, allowing him to reconstruct from the union of the two information. In this new context, the need to review the traditional concepts of teaching and learning prevails. Teaching, basically, would be creating the conditions for the student to construct meanings. And in this last action the new conception of learning would consist fundamentally. It is here where the theory of meaningful learning intervenes to facilitate the transition to this new educational paradigm. According to the theory of significant learning, learning is a reconstruction of knowledge already developed and the learning subject is an active processor of information and the ultimate responsible for such learning, with the participation of the teacher as a facilitator and mediator of the same and, most importantly, provider of all the pedagogical help that the student requires [3].

From Ausubel's constructivist perspective, the conceived learning process is one by which the learning subject processes information in a systematic and organized way and not only in a memorized way, but also constructs knowledge [4].

The importance of applying the knowledge of physics acquired in class to achieve significant learning, motivated students and teachers in the design and construction of a prototype of standing waves, since the Technological University of Tlaxcala (UTT) does not have equipment for this type for real-time testing. The interest in this prototype is to leave the following generations a device to provide feedback on engineering physics topics and contribute to equipping a physics laboratory at UTT where students and teachers improve the prototype or design others to achieve learning experiences.

The design of the prototype was based on the existing information on the generation of standing waves by means of different devices, developed by different authors [1], [2], [5], [6]. We know that, with a fixed rope at both ends, standing waves can be formed so that the end points are always nodes. The string can oscillate in different ways called vibration modes. The generated device has the characteristic of being constructed with materials of easy access and low cost, consisting mainly of a vibrating motor, a rope, a support and a dynamometer to measure the tension of the rope.

1.1 Wave terminology

The most important concepts in wave motion are [7], [8].

Propagation speed (*v*). It is the space that the wave travels per unit of time. The speed of a wave motion depends on the type of wave in question and the medium by which spread. Sound propagates through a physical medium (solid, liquid or gas) and its speed depends on the medium.
Period (***T***). It is the time it takes for a wave to make a full swing.
Wavelength (λ). It is the length (in length) that a wave has complete, see figure 1.
Frequency (***f***). It is the number of complete oscillations that performs one particle per unit time. Its unit is the Hertz (Hz), with one Hertz equal to one full oscillation every second. According to the definition of period, given that an oscillation lasts *T* seconds, in one second there will be *1/T* oscillations, therefore: $f = 1/T$, that is, the frequency is the inverse value of the period.
Phase agreement. It is said that two points of a medium elastic by which a wave propagates are in agreement phase if, at a given moment, the two points occupy identical positions and move the same way (up or down). Points **A** and **B** of figure 1 are in agreement phase, but not the **C**, since, although it is at the same height is going down instead of going up as A and B. Then the length of a wave will be the distance that separates two successive phase matches.
Amplitude (***A***). It is the maximum separation that the wave reaches regarding its equilibrium position. It is represented as ***A***.

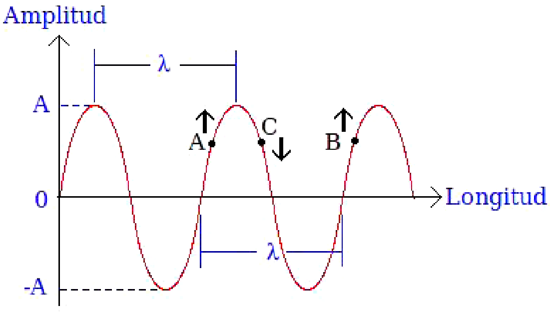


Figure 1. Components of a transverse wave.

If period T is the time to travel a distance of one wavelength. Therefore, the wave speed is:

$$v = \frac{\lambda}{T} \; but \; T = \frac{1}{f} \; then,$$

$$v = \frac{\lambda}{\frac{1}{f}} \; thus, v = f\lambda$$

$$v = f\lambda$$

This relationship is valid for all waves, not just for waves on a string.

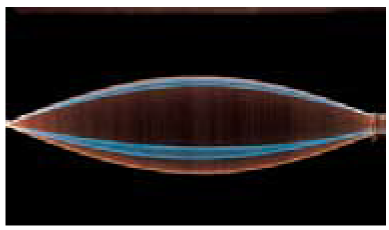
1.2 Standing waves

Standing waves are produced by the interference of two waves of the same nature (with the same amplitude, wavelength or frequency) that advance in the opposite direction through a medium. Standing waves remain confined in a space (string, tube with air, membrane). The amplitude of the oscillation for each point depends on its position, the frequency is the same for everyone and coincides with the interfering waves. They have non-vibrating points called (nodes), represented by ***N***, that remain motionless or stationary, while others (bellies or antinodes) labeled by ***A***, do so with a maximum vibration amplitude equal to twice the interfering waves, and with maximum energy. The standing wave name comes from the apparent immobility of the nodes. The distance between two nodes or two antinodes is the half wavelength. A standing wave are not propagation waves but different modes of vibration of the string.

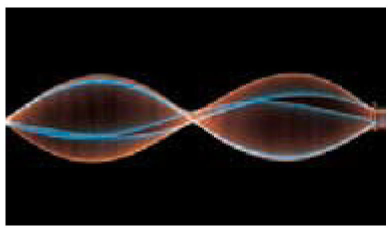
For a string, there are only certain frequencies at which standing waves are produced which are called resonance frequencies. The lowest is called the fundamental frequency, and the rest are integer multiples of it (double, triple, ...) [9].
Figure 2 shows the formation of standing waves on a string of length ***L***, attached to its left end.

Figure 2. a) to d) Successive exposures of standing waves on a stretched string. From a) to d), the oscillation frequency of the end right increases, and the length of the standing wave decreases. e) The ends of the motion of the standing wave of b), with nodes in the center and at the ends. The right end of the rope moves very little compared to the antinodes, so it is practically a node [10].

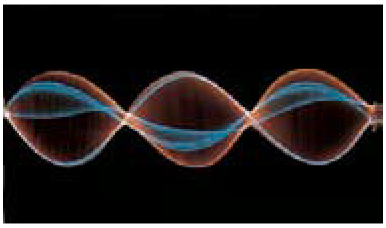
a) The string has half a wavelength



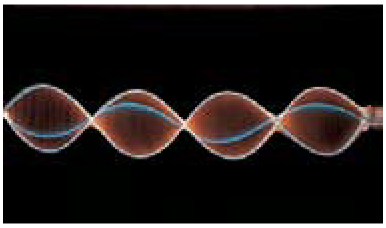
b) The string is of a wavelength



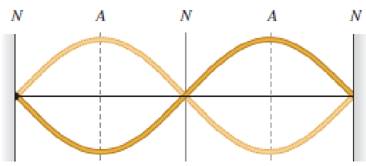
b) The string is one and a half wavelengths



c) The string is two wavelengths



e) The shape of the rope in b) at two different moments



N = nodes: points where the rope never moves.

A = Antinodes: points where the amplitude

As can be seen in figure 2, the different vibration modes of a string under tension are shown, in which the vibration mode 1 is called the fundamental or first harmonic mode (***n = 1***), when two nodes are produced it is called the second mode vibration or second harmonic (***n = 2***), and so on. The string length is $L = \lambda / 2$ in the fundamental mode, while in the second vibration mode the wavelength is $L = 2\lambda / 2 = \lambda$, in the third vibration or third harmonic mode the string length is $L = 3\lambda / 2$, in the fourth harmonic $n = 4$, the string length will be $L = 4\lambda / 2 = 2\lambda$ and so on. In general, it is established that the wavelength is given by the equation:

$$L = \frac{n\lambda}{2}$$

Clearing λ from the above equation, the wavelength for n harmonics remains:

$$\lambda = \frac{2L}{n}\ para\ n = 1, 2, 3, \ldots$$

Where the wavelength is measured in meters, (m).

We know that $v = f\lambda$, clearing **f** from the equation the resonant frequencies corresponding to these wavelengths are given by:

$$f_n = \frac{vn}{2L} \qquad n = 1, 2, 3, \ldots$$

Where:

f = resonant frequency (Hz), n = harmonic number of the nth wave, v = velocity of the wave in the string (m/s).

The velocity of the **v** wave is determined with the following formula:

$$v = \sqrt{\frac{F}{\mu}}$$

Where:

v = wave velocity (m/s), F = string tension (Newton)

μ = string linear density = mass / Length = m/L, (kg/m).

In accordance with the above, the characteristic frequencies depending on the tension of the string and its length are given by:

$$f_n = \frac{vn}{2L} = \frac{n}{2L} \cdot v = \frac{n}{2L}\sqrt{\frac{F}{\mu}}$$

So;

$$f_n = \frac{n}{2L}\sqrt{\frac{F}{\mu}} \qquad para\ n = 1,2,3, \ldots$$

Now, solving for F from the previous equation, the tension force necessary to create n harmonics will be:

$$F = \frac{4\mu L^2 f^2}{n^2}\ \ para\ \ n = 1,2,3, \ldots$$

2. DESCRIPTION OF THE METHOD

The prototype of standing waves was developed by the seventh semester students of the Industrial Maintenance Engineering degree, at the facilities of the Technological University of Tlaxcala in the welding and pailer shop.

The tool and material that was used to prepare the equipment is shown in Tables 1 and 2 respectively. After this the manufacturing process is shown.

Table 1. Tools for manufacturing the prototype.

Tool list		
Quantity	Tool	Type
01	Drill	------------
01	drill bit	3/8 inch
01	drill bit	1/4 inch
05	Taps	-------------
01	Welding machine	Micro wire
02	Gloves	Bait
01	Mask	Electric
01	Painting	Aerosol
01	Polisher	------------
01	Polishing disc	Cutting
01	Polishing disc	To polish
01	Flexometer	------------
01	Screw	bank
01	Bow with hacksaw	------------
01	Squad	9 inch
01	Cutter	Manual
01	Screwdriver	cross
01	Riveter	------------

Table 2. Material to build the prototype

Material list for the prototype		
Quantity	Material	Type
02	Sheet	Stainless steel
04	Solera	------------
01	Screw	Hexagonal
01	Nut	Hexagonal
01	Motor	AC 115V
01	Dynamometer	12 kg
01	Pulley	V
01	Round tube	Hole
01	Round tube	Solid
01	Balero	608ZZ
04	Plastics	Acrylic
04	Screw	cross
01	Rope	Cotton

Because the vibrating motor is alternating current (AC), it was necessary to equip it with a triac (Triode for Alternating Current) to allow us to regulate the speed of the motor.

The manufacturing process of the standing wave prototype is shown in the following figures:

1. The stainless steel sheet for the prototype support base was cut (See figure 3).

Figure 3. Base cut.

2. Solera cuts were made to reinforce the base. (according to figure 4).

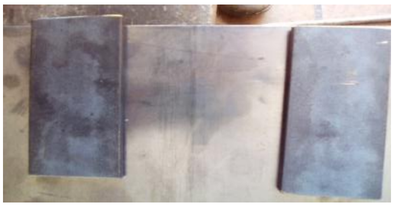


Figure 4. Screed cuts.

3. Subsequently the screeds are welded on our base at 90 ° (figures 5 and 6).

Figure 5. Welding screeds.

Figure 6. Measurement at 90-degree angle

4. Rear sheet soldier, which will act as a wall in our prototype. (figure 7).

Figure 7. Sheet wall

5. Polishing of weld (figure 8)

Figure 8. Weld polishing.

6. Prototype base (figure 9).

Figure 9. Prototype base.

7. The hexagonal screw is welded to our tube. (See figure 10).

Figure 10. Pipe welded screw.

8. The center is found at the base and a hole was made with the drill and the ¼ bit. (See figure 11).

Figure 11. Hole at the base.

9. This hole was made to be able to manipulate our tube with the welded screw (this will look like figures 12 and 13).

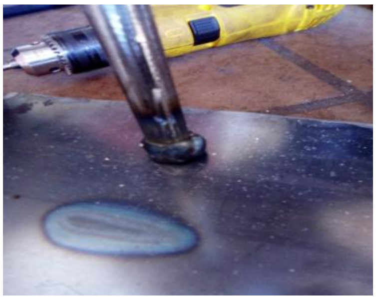


Figure 12. Tube inserted into hole.

Figure 13. Nut below the base.

10. Two pieces of approximately 10 cm hollow tube were cut. And they are joined by welding to form the base of the motor (Figures 14, 15 and 16).

Figure 14. Welded tubes.

Figure 15. Placement of motor base.

Figure 16. Tapping for motor base

11. The pulley was welded to the sill, so that the rope passes. (See figure 17.)

Figure 17. Pulley welded to the sill to pass the tensioned rope.

12. The hearth is welded with the pulley to the tube, leveling at the height of the arrow on the motor, and then the dynamometer is welded to the hollow tube (See figures 18 and 19).

Figure 18. Welding of the pulley to the tube.

Figure 19. Dynamometer to measure string tension.

All of the above was done following the drawings of the AutoCAD design of the standing wave prototype (according to figure 20).

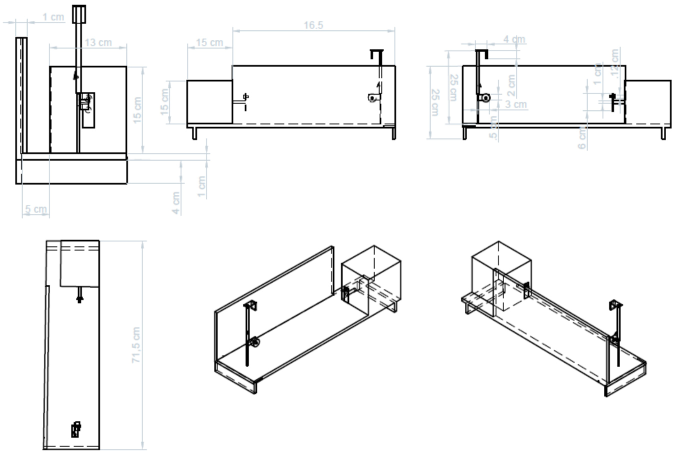


Figure 20. Prototype design in AutoCAD.

3. RESULTS

Figure 21 shows the standing wave equipment already assembled and commissioned. Where the formation of 4 harmonics with its corresponding tension force that marks the dynamometer is clearly observed. It is worth mentioning that varying the motor revolutions and the tension force in the string can be generated from the fundamental harmonic and "n" harmonics as shown in Table 3.

Figure 21. Operation and start-up of standing wave equipment.

Table 3. Harmonic data in the standing wave prototype.

Results of experiment at 8 harmonics, with chord length, *L* = 0.74 m, and chord mass, *m* = 0.003543 kg.			
n	string tensión (N)	Linear density μ (kg/m)	Wavelength λ (m)
3	2,89	0.00478	0,493
4	1,93	0.00478	0,370
5	1,2	0.00478	0,296
6	0,68	0.00478	0,246
7	0,48	0.00478	0,211
8	0,20	0.00478	0,185

According to Table 3, the string tension decreases with increasing number of harmonics as the standing wavelength decreases.

4. CONCLUSIONS

The evidence shown above shows that for the formation of standing waves it depends on the tension of the string, as well as the revolutions per minute of our motor. For the reasons mentioned, it is clear that there is a balance between motor power and string tension.

The standing wave generation physics class with the deduction of its formulas and problem solving was carried out on a blackboard without the prototype, achieving an understanding of 35 percent. Once the prototype was built, the topic was fed back, achieving 100 percent understanding by the students, which shows that with the support of didactic teams to reinforce theory with practice, significant learning is achieved.

It is intended to leave a prototype that will serve the following generations, with the only warning: this prototype is available to the University, as well as the care and maintenance that the prototype requires at a future time, as well as whether the University Authorities They consider it pertinent to start the patent process.

Students always have fresh ideas that contribute together with the teacher to generate innovative projects that result in the integral teaching-learning process, essential in the training of successful professionals. I sincerely appreciate your enthusiasm and selfless participation.

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