MODULE 15

STANDING WAVES ON A STRING 2

1. PURPOSE
1.1. Determines the harmonic frequency due to standing wave on the string
1.2. Determines the velocity of standing wave on the string
1.3. Determines factors that affect the velocity of standing wave on the string

2. TOOLS
2.1. LabQuest2 (1 pc)
2.2. Vibrator (1 pc)
2.3. Power amplifier (1 pc)
2.4. Pulley (1 pc)
2.5. Cable Connector (2 pcs)
2.6. Ruler (1 pc)
2.7. Digital scales (1 pc)
2.8. Statif (1 pc)
2.9. Hanging load (9 pcs)
2.10. Thick string (1 pc)
2.11. Thin string (1 pc)
2.12. Green string (1 pc)
2.13. Brown string (1 pc)

Figure 15.1. Tools used.

3. BASIC THEORY
A wave is a vibration that propagates in a medium, which carries energy from one place to another and is not followed by the movement of the intermediate particles. Waves are divided into two types based on the medium, namely electromagnetic waves and mechanical waves. Electromagnetic waves are waves that propagate without going through a medium or intermediary, for example: light waves. Meanwhile, mechanical waves are waves that propagate through a medium or intermediary.

Mechanical waves can be divided into two types based on the direction of motion of the particles against the direction of wave propagation, namely:

a. Longitudinal waves are waves that propagate in the direction of the vibration of the particles. Example: a longitudinal wave is a wave on a spring.

b. Transverse waves are waves that propagate perpendicular to the direction of vibration of the particles. Example: a transverse wave is a wave on a string.

If a string with a certain tension is vibrated continuously, it will be seen a wave form whose direction of vibration is perpendicular to the direction of wave propagation. These waves are called transverse waves. If both ends are closed, then the waves on the rope will bounce and can produce stationary waves that appear in the form of knots and belly waves. Melde's experimental design is as follows.

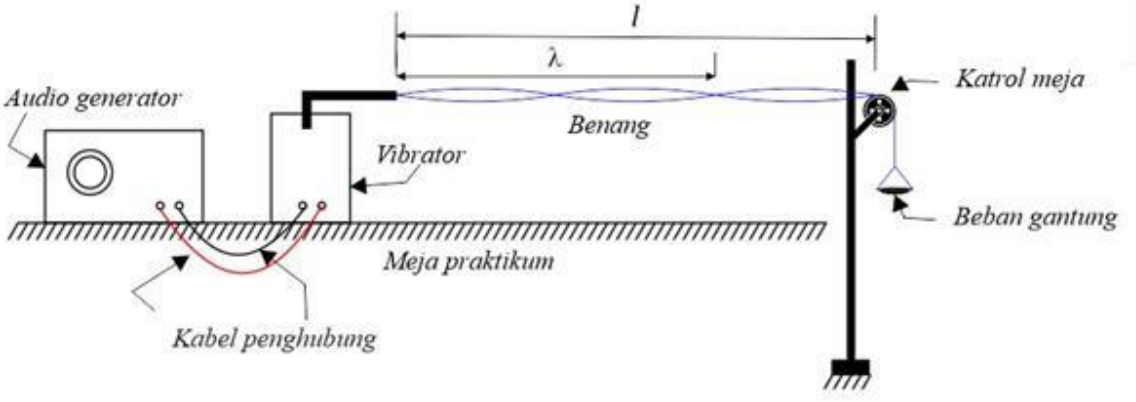

Figure 15.2. Melde's experimental design.

Stationary waves, also known as standing waves, standing waves or stationary waves, are waves formed by the combination or interference of two waves that have the same amplitude and frequency but have opposite directions of propagation. The amplitude of a stationary wave is not constant, the magnitude of the amplitude at any point along the wave is not the same. At the node the amplitude is equal to zero and at the belly of the wave the amplitude is maximum. The following is an illustration of a stationary wave with a fixed end.

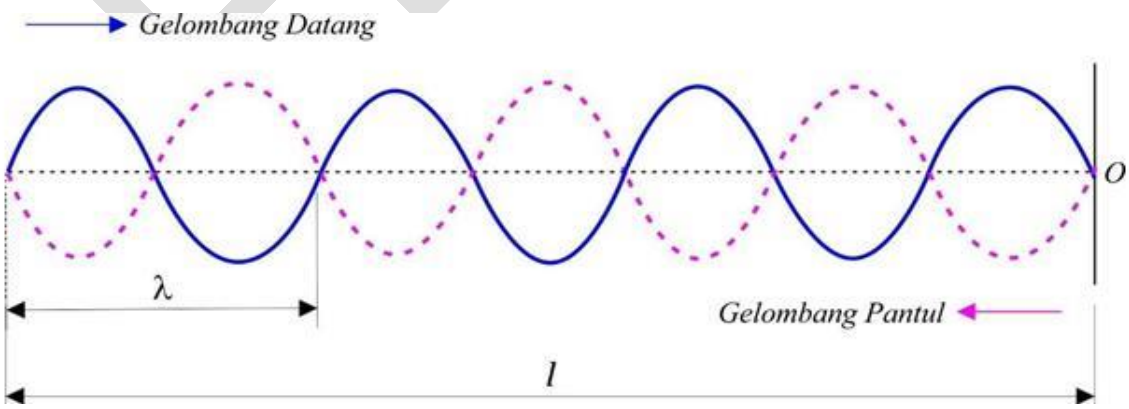

Figure 15.3. Illustration of a stationary wave with a fixed end.

From the figure above, it is obtained that the wavelength is

$$\lambda = \frac{l}{n} \tag{15.1}$$

with

λ : wavelength (m)

l : string length (m)

n : number of waves

The wave period (T) is the time it takes for the wave to travel one full wave. Wavelength (λ) is the distance the wave travels in one time. Frequency (f) is the number of waves that occur per unit time. The relationship between period and frequency is:

$$T = \frac{1}{f} \tag{15.2}$$

The wave velocity (v) is the distance traveled by the wave per unit time. In general, the velocity of a stationary wave can be found by the equation:

$$v = \lambda \times f \tag{15.3}$$

or

$$v = \frac{\lambda}{T} \tag{15.4}$$

with

v : wave velocity (m/s)

λ : wavelength (m)

f : frequency of waves (Hz)

T : wave period (s)

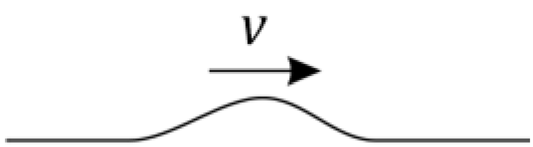

Figure 15.4. Waves travelling on a string.

In a case where a wavepulse travels on a string as of figure 15.4, the propagation of stationary wave pulses with velocity v can be analyzed by observing the distance traveled by the rope segment (Δs) which is illustrated in the following figure.

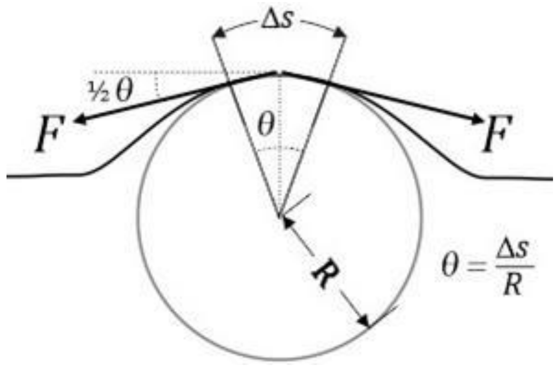

Figure 15.5. Wave propagation analysis.

This wave pulse is a segment of the circular motion which has a centripetal acceleration

$$a = \frac{v^2}{R} \tag{15.5}$$

The segment of element's string (Δs) can be expressed by:

$$\theta = \frac{\Delta s}{R} \rightarrow \Delta s = \theta \times R \tag{15.6}$$

As figure 15.5, the resultan of radial force gives sentripetal acceleration as follow:

$$\sum F = 2\,F \sin\frac{\theta}{2} \tag{15.7}$$

For a small value of θ, applies $\sin\theta \approx \theta$, hence:

$$\sum F = F\theta \tag{15.8}$$

Besides that, mass of wire length is defined as

$$\mu = \frac{m}{\Delta s} \rightarrow m = \mu \times \Delta s \rightarrow m = \mu \times \theta \times R \tag{15.9}$$

Thus, the resultan of force could defined as:

$$\sum F = F\theta = m \times a \times \mu = \mu\theta R \times \frac{v^2}{R} \rightarrow F\theta = \mu\theta R \times \frac{v^2}{R} \tag{15.10}$$

Then,

$$v = \sqrt{\frac{F}{\mu}} \tag{15.11}$$

with

v : wave velocity (m/s)

F : stress (N)

μ : mass of string length union (kg/m)

4. EXPERIMENT

4.1. Experiment Set Up

1. Measure load mass and write it on table 15.1.
2. Measure the length and the mass of the rope , determine mass per length and put it in table 15.2.

Table 15.1. Load Mass.

	Load Mass (kg)
Hook	...
1	...
2	...
...	...
N	...

Table 15.2. Mass and string measurement data.

String	Mass (kg)	Length (m)	μ (kg/m)
A			
B			
C			

3. Make sure the tool is attached as shown in Figure 15.1. (consult with an assistant) to a rope of a length of 100 cm.
4. Turn the **ON** button on the power amplifier.
5. Connect Speaker Out on LabQuest2 and Audio In on power amplifier using mini stereo cable.
6. On the LabQuest2 Home menu, select ”Power Amplifier”. Set 2.0 VAC and change the frequency to a value around 20 Hz.
7. Click Start, use the up and down symbols to set the frequency value so as to get the first harmonic frequency (half wave full) which will be used as input parameter.

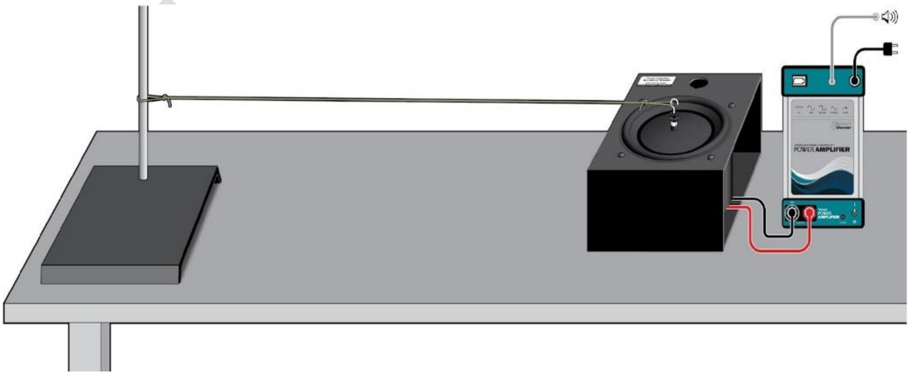

Figure 15.6. Experimental schematic.

4.2. **Determining Harmonic Frequency**

1. Make sure the tool stays wired as shown in Figure 15.6.
2. Adjust the frequency until it produces the first harmonic ($\frac{1}{2}\lambda$) which is the largest amplitude in the middle and the knot at the end. As the optimal frequency approaches, make adjustments gradually and wait a few seconds after making adjustments for the system to stabilize.
3. Record the frequency as f_1.
4. Without changing the length of the string, increase the frequency gradually so that you get the second harmonic ($f_2(\lambda)$), third harmonic($f_3(\frac{3}{2}\lambda)$) and fourth harmonic ($f_4(2\lambda)$).
5. Draw a waveform and record the value of the frequency, maximum amplitude and wavelength at each harmonic frequency.
6. Calculate the value of the wave propagation speed of each harmonic frequency. Also calculate the average speed of wave propagation and the standard deviation of the data obtained from each rope.
7. Repeat steps 1-6 using a different type of rope.

Tabel 15.3. Harmonic Frequency Experiment Data.

f(Hz)	f_1	f_2	f_3	f_4
1/f (s)				
λ (m)				
A (m)				
v (m/s)				

4.3. **Factors Affecting Standing Wave Propagation Speed on a String**

1. Tie the rope on the speaker hook and at the end of the pulley, add the weight as a hanger as shown in Figure 15.7. Count the length of the string from the speaker hook to the string in contact with the pulley by 100 cm.

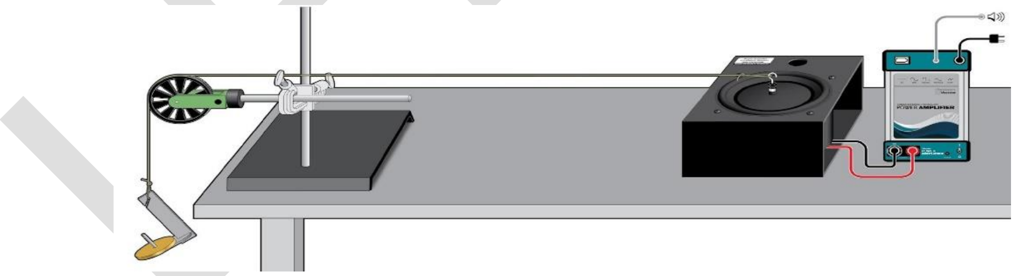

Figure 15.7. Set up with added load.

2. Adjust the frequency so that you get the fourth harmonic or waveform that is easily observable.
3. Without changing the frequency value, do the addition of the load then record the value of mass and λ.
4. Determine the value of the tension in the rope (F) and the speed of the wave (v).
5. Do linear regression F vs v^2 and then determine the value of the rope density from the linear regression results obtained. Also calculate the error to the value of the rope density obtained at the beginning.
6. Do steps 1-5 with different rope types

Tabel 15.4. Experiments Data on factors affecting standing wave propagation speed.

Frequency (Hz)	Period (seconds)	Mass (kg)		λ (m)	T ($kg.m/s^2$)	v (m/s)	V^2 (m^2/s^2)

5. ANALYSIS

5.1. Explain whether the Melde's Law can be proven through this experiment!

5.2. How to ensure that the standing waves on a string is stringrly observed?

5.3. What changes to the waves can be observed when weight is added? Explain why this happen!

5.4. In Experiment 1, what changes happen to the wave when frequency is increased? Can the n-harmonic frequency be determined?

5.5. Can the amplitude change when you change in either frequency, load mass or rope density? If it can, please explain why, if not which parameter in this experiment that influence it?

6. REFERENCE

D. Halliday, R. Resnick, and J. Walker, Fundamentals of Physics (Extended), 8th edition, John Wiley & Sons (2008).

L. Dukerich, Advanced Physics with Vernier – Beyond Mechanics, Vernier Software and Technology.

M. Abdullah. Fisika Dasar II, Penerbit ITB (2007).