Energy and Electrical Systems Engineering Program
Mechatronics Engineering Program

Tanta University | Faculty of Engineering

Course Title	Engineering Physics (III)	Final Exam	Course Code	EMP X43
Date:	10/7/2024	No. of Pages: 2	Allowed time	120 min

Answer the following questions (Total Marks 20)

Question (1) (25 Marks)

(1-1) A transverse sinusoidal wave on a string has a period T = 25 ms and travels in the negative x direction with a speed of 30.0 m/s. At t = 0, an element of the string at x = 0 has a transverse position of 2.00 cm and is traveling downward with a speed of 2.00 m/s. (a) What is the amplitude of the wave? (b) What is the initial phase angle? (c) What is the maximum transverse speed of an element of the string? (d) Write the wave function for the wave (3 Marks)

$$y(x,t) = A\sin(kx + \omega t + \phi) \qquad y_i = y(0,0) = A\sin\phi = 0.02 \text{ m}$$

$$v_i = v(0,0) = \left.\frac{\partial y}{\partial t}\right|_{0,0} = A\omega\cos\phi = -2.00 \text{ m/s} \qquad \omega = \frac{2\pi}{T} = \frac{2\pi}{0.025} = 80.0\pi \text{ s}^{-1}$$

$$\sin^2\phi + \cos^2\phi = 1 \qquad \frac{(A\sin\phi)^2}{A^2} + \frac{(A\omega\cos\phi)^2}{A^2\omega^2} = 1$$

$$(A\sin\phi)^2 + \frac{(A\omega\cos\phi)^2}{\omega^2} = A^2$$

$$A^2 = y_i^2 + \left(\frac{v_i}{\omega}\right)^2 = (0.02\ )^2 + \left(\frac{-2}{80\ \pi}\right)^2 \qquad A = \boxed{0.021\ 5 \text{ m}}$$

$$\frac{\omega y_i}{v_i} = \frac{\omega(A\sin\phi)}{\omega A\cos\phi} = \tan\phi \qquad \tan\phi = \frac{80.0\pi(0.020\ )}{-2} = -2.51$$

$$\phi = \tan^{-1}(-2.51) = -1.19$$

The angle in the second quadrant is

$$\phi = \pi - 1.19 \text{ rad} = \boxed{1.95 \text{ rad}}$$

$$v_{y,\max} = A\omega = (0.021\ 5\ )(80\ \ \pi\ ) = \boxed{5.41 \text{ m/s}}$$

$$\lambda = v_x T = (30\ )(0.025) = 0.750 \text{ m}$$

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.75} = 8.38 \text{ m}^{-1} \qquad \omega = 80.0\pi \text{ s}^{-1}$$

$$\boxed{y(x,\ t) = (0.021\ 5)\sin(8.38x + 80.0\pi t + 1.95)}$$

(1-2) A string that is taut under tension of magnitude τ = 40 N has a linear density μ of 64 g/m. A wave is traveling along the string with a frequency f of 120Hz and amplitude A of 8mm. (a) Find the speed of the wave. (b) What is the rate of energy that must be supplied by a generator to produce this wave in the string? (c) If the string is to transfer energy at a rate of 500W, what must be the required wave amplitude when all other parameters remain the same? (3 Marks)

(a)
$$v = \sqrt{\frac{\tau}{\mu}} = \sqrt{\frac{40}{0.064}} = 25 \text{ m/s}$$

(b)
$$\omega = 2\pi f = 2 \times (3.1416) \times (120) = 754 \text{ rad/s}$$

$$P = \tfrac{1}{2}\mu v \omega^2 A^2 \Rightarrow P = \tfrac{1}{2}(0.064)(25)(754)^2(0.008)^2$$

$$P = 29.1 \text{ W}$$

(c)
$$\frac{P'}{P} = \frac{\frac{1}{2}\mu v \omega^2 A'^2}{\frac{1}{2}\mu v \omega^2 A^2} = \frac{A'^2}{A^2} \Rightarrow A' = A\sqrt{\frac{P'}{P}} = 0.008\sqrt{\frac{500}{29.1}} = 0.033 \text{ m} = 3.3 \text{ cm}$$

(1-3) At a frequency of 1,000 Hz, the human ear can detect the loudest and faintest sounds with intensities of about 1.0 W/m2 and 1.0×10^{-12} W/m^2, respectively. For sound waves traveling with a speed of v = 343 m/s, find the pressure amplitude ΔP_{max} for the faintest and the loudest sound waves, assuming the air's density is ρ = 1.21 kg/m^3 (3 Marks)

The pressure amplitude ΔP_{max} for the faintest sound waves

$$\Delta P_{max} = \sqrt{2\rho v I} = \sqrt{2(1.21 \text{ kg/m}^3)(343 \text{ m/s})(1 \text{ W/m}^2)}$$

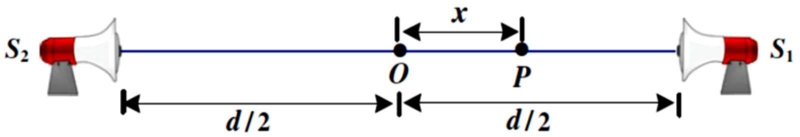
$$\Delta P_{max} = 28.8 \text{ N/m}^2 = 28.8 \text{ Pa} \qquad \text{(Loudest; threshold of pain)}$$

The pressure amplitude ΔP_{max} for the loudest sound waves

$$\Delta P_{max} = \sqrt{2\rho v I} = \sqrt{2(1.21 \text{ kg/m}^3)(343 \text{ m/s})(1 \times 10^{-12} \text{ W/m}^2)}$$

$$\Delta P_{max} = 2.88 \times 10^{-5} \text{ N/m}^2$$

(1-4) Two identical speakers, S_1 and S_2, are placed horizontally at a distance d =2m apart. Each emits sound waves of wavelength λ=80 cm driven by the same oscillator. A listener is originally located at point O, which is midway between the two speakers. The listener walks to point P, which is a distance x from O, and reaches the first minimum in sound intensity. Find x. (4 Marks)



If L_1 and L_2 are the distances from S_1 and S_2 to point P, respectively, then according to Fig. we have:

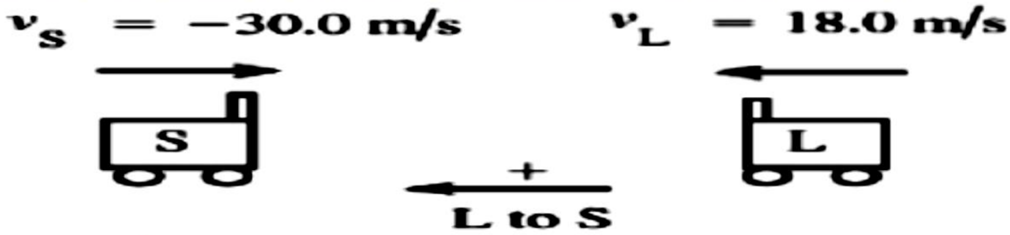
$$L_1 = \frac{d}{2} - x \qquad L_2 = \frac{d}{2} + x$$

$$|L_2 - L_1| = \frac{\lambda}{2} \Rightarrow \left|\left[\frac{d}{2} + x\right] - \left[\frac{d}{2} - x\right]\right| = \frac{\lambda}{2}$$

$$x = \frac{\lambda}{4} = \frac{80\,\text{cm}}{4} = 20\,\text{cm}$$

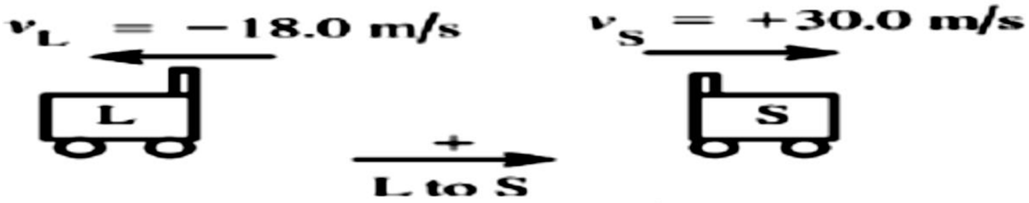
(1-5)A railroad train is traveling at 30.0 m/s in still air. The frequency of the note emitted by the train whistle is 352 Hz. What frequency is heard by a passenger on a train moving in the opposite direction to the first at 18.0 m/s and (a) approaching the first and (b) receding from the first?

a) The positive direction is from the listener toward the source



$$f_L = \left(\frac{v + v_L}{v + v_S}\right) f_S = \left(\frac{344\text{ m/s} + 18.0\text{ m/s}}{344\text{ m/s} - 30.0\text{ m/s}}\right)(352\text{ Hz}) = 406\text{ Hz}$$

b)



$$f_L = \left(\frac{v + v_L}{v + v_S}\right) f_S = \left(\frac{344\text{ m/s} - 18.0\text{ m/s}}{344\text{ m/s} + 30\ \ \text{m/s}}\right)(352\text{ Hz}) = 307\text{ Hz}$$

(1-6)The fundamental frequency of a pipe that is open at both ends is 588 Hz. (*a*) How long is this pipe? If one end is now closed, find (*b*) the wavelength and (*c*) the frequency of the new fundamental. Take v =343 m/s as the speed of sound in air. (4 Marks)

(*a*) **For an open pipe,** $f_1 = \frac{v}{2L}$. **For a stopped pipe,** $f_1 = \frac{v}{4L}$. $v = f\lambda$.

(*b*) $$L = \frac{v}{2f_1} = \frac{344\text{ m/s}}{2(524\text{ Hz})} = 0.328\text{ m}.$$

There is a node at one end, an antinode at the other end and no other nodes or antinodes in between

$$\lambda_1 = 4L = 4(0.328\text{ m}) = 1.31\text{ m}$$

(*c*) $$f_1 = \frac{v}{4L} = \frac{1}{2}\left(\frac{v}{2L}\right) = \frac{1}{2}(524\text{ Hz}) = 262\text{ Hz}.$$

We could also calculate f_1 for the stopped pipe as

$$f_1 = \frac{v}{\lambda_1} = \frac{344\text{ m/s}}{1.31\text{ m}} = 262\text{ Hz}$$

Which agrees with our result in part (c)

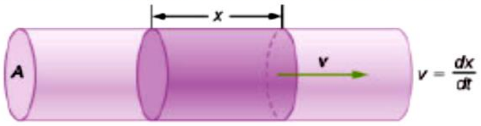
(1-7) prove that: the speed of sound in ideal gas is equal to $v = \sqrt{\frac{\gamma RT}{M}}$

where T is the Kelvin temperature, M is the molar mass, and *R* is gas constant where γ = is the ratio of the specific heat capacity at constant pressure to the specific heat capacity at constant volume (4 Marks)

Consider fluid flow through a pipe with cross-sectional area A. The mass in a small volume of length x of the pipe is equal to the density times the volume

$m = \rho V = \rho A x.$ The mass flow rate is

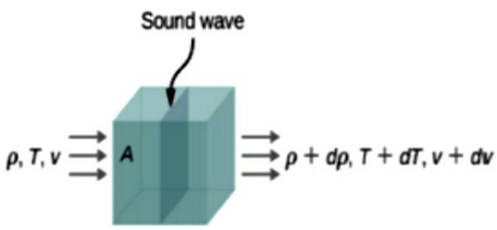
$$\frac{dm}{dt} = \frac{d}{dt}(\rho V) = \frac{d}{dt}(\rho A x) = \rho A \frac{dx}{dt} = \rho A v.$$



the mass flow rate into a volume has to equal the mass flow rate out of the volume,

$$\rho_{in} A_{in} v_{in} = \rho_{out} A_{out} v_{out}$$

Now consider a sound wave moving through a parcel قطعة of air. A parcel of air is a small volume of air with imaginary boundaries . The density, temperature, and velocity on one side of the volume of the fluid are given as ρ, T, v, and on the other side are $\rho + d\rho$, $T + dT$, $v + dv$



The continuity equation states that the mass flow rate entering the volume is equal to the mass flow rate leaving the volume, so $\rho \cancel{A} v = (\rho + d\rho)\cancel{A}(v + dv)$

the multiplication of two infinitesimals is approximately equal to zero: $d\rho dv \approx 0$

$$\cancel{\rho v} = (\rho + d\rho)(v + dv) \quad = \cancel{\rho v} + \rho(dv) + (d\rho)v + \cancel{(d\rho)(dv)}$$

$$0 = \rho(dv) + (d\rho)v \quad \Rightarrow \quad \rho\, dv = -v\, d\rho$$

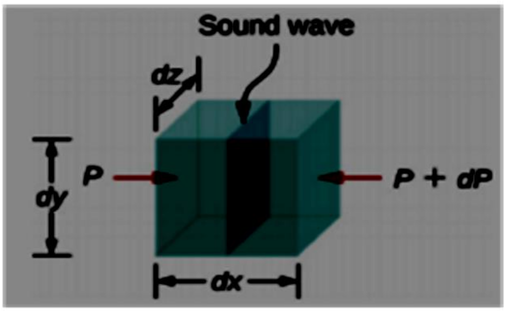
The net force on the volume of fluid equals the sum of the forces on the left face and the right face:

$$F_{net} = p\, dy\, dz - (p + dp)\, dy\, dz = p\, \cancel{dy}\, dz \; - p\, \cancel{dy}\, dz - dp\, dy\, dz \quad = -dp\, dy\, dz$$

$$ma = -dp\, dy\, dz$$

The acceleration is the force divided by the mass and the mass is equal to the density times the volume, *$m = \rho V = \rho\, dx\, dy\, dz$*

$$ma = -dp\, dy\, dz$$



$$\frac{dp}{d\rho} = \frac{\gamma p}{\rho} \quad \Rightarrow \quad pV = nRT = \frac{m}{M}RT \quad \Rightarrow \quad p = \frac{m}{V}\frac{RT}{M} = \rho\frac{RT}{M}$$

$$\frac{dp}{d\rho} = \frac{\gamma p}{\rho} = \frac{\gamma\left(\cancel{\rho}\frac{RT}{M}\right)}{\cancel{\rho}} = \frac{\gamma RT}{M} \quad \Rightarrow \quad v = \sqrt{\frac{dp}{d\rho}} \quad \Rightarrow \quad v = \sqrt{\frac{\gamma RT}{M}}$$

the speed of sound depends on the properties of the medium

Ideal gas $\qquad v = \sqrt{\dfrac{\gamma kT}{m}}$

Ratio of heat capacities · Gas constant

Speed of sound in an ideal gas $\quad v = \sqrt{\dfrac{\gamma RT}{M}}$ Absolute temperature · Molar mass

- where T is the Kelvin temperature, m is the mass of a molecule, and k is Boltzmann's constant where $\gamma = c_P/c_V$ is the ratio of the specific heat capacity at constant pressure c_P to the specific heat capacity at constant volume c_V

γ has the value of *5/3* for ideal monatomic gases and a value of *7/5* for ideal diatomic gases

Question (2) **(25 Marks)**

End of questions

Best wishes - Examining committee