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ME 513

Exam 1 – Fall 2017 -- 11/10/2017

Note: To help you complete this exam, you may refer to your class notes, your homework, solutions provided to you and other material distributed as part of the course either in-class or *via* the course website, but you may not refer to the text (Kinsler, Frey, Coppens and Sanders) or to any other acoustics text in either hardcopy or electronic form, and connection to the internet is not allowed.

- Problem 1: __________/20
- Problem 2: __________/20
- Problem 3: __________/20

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Problem 1.

(i) What is sound?

(ii) For free oscillations to occur, a physical system must have both ____________________ and ______________________ .

(iii) The motion of the mass in a SDOF system is governed by a second order, ordinary differential equation. As a result, the solution features ________________________________ that must be determined by application of initial conditions.

(iv) The time phasor $e^{-j\omega t}$ can be represented in the complex plane by a vector that rotates in the __________________________________ direction.

(v) What are the characteristics of a stiffness-like mechanical impedance?

(vi) What physical property of a SDOF system controls its forced response at frequencies well above the resonance frequency?

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(vii) In the expression e^{jkx}, k is the rate of increase of ____________________ with ________________________.

(viii) The restoring force acting on a segment of a tensioned string is not proportional to the slope of the segment: instead, it is proportional to

____.

(ix) In the calculation of sound pressure levels, why was the reference root mean square sound pressure chosen to be 2×10^{-5} Pa?

(x) Why is a spherically-symmetric wave expanding into free space referred to as a one-dimensional wave?

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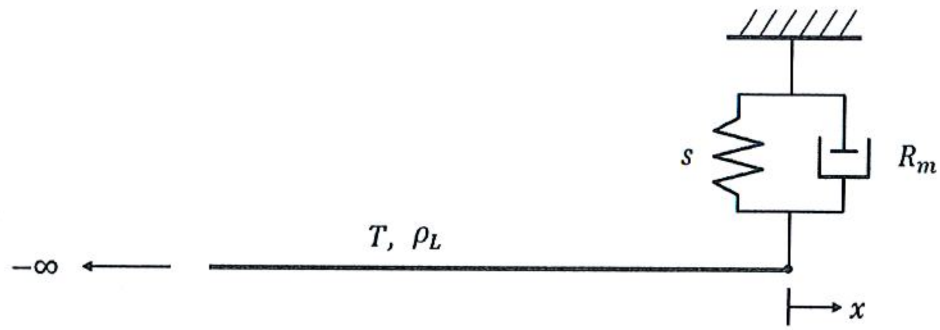
Problem 2.

A unit amplitude transverse wave having a displacement given by

$$y(x,t)=e^{j(\omega t-kx)}$$

propagates along a semi-infinite, uniformly tensioned string that is terminated at $x = 0$ by a spring and a viscous damper, as shown below. The tension in the string is T, its mass per unit length is ρ_L, the spring stiffness is s, the mechanical damping is R_m, and all of these parameters are real.



(i) Give an appropriate assumed solution for the total displacement field of the string, and define quantities as necessary.

(ii) Draw the free body diagram that applies at $x = 0$.

(iii) Give the boundary condition at $x = 0$ in equation form.

(iv) By using the boundary condition, solve for the complex amplitude of the wave that is reflected from the termination, and express the result in terms of the characteristic impedance of the string.

(v) What combination of parameter values would result in zero reflection from the termination?

(i) $y(x,t) = e^{-jkx}e^{j\omega t} + B e^{+jkx} e^{j\omega t}$ $\qquad k = \frac{\omega}{c} \qquad c = \sqrt{T/\rho_L}$

(ii) T θ $-sy - R_m \frac{dy}{dt}$

(iii) $\Sigma f_y = 0 \quad T\sin\theta\big|_{x=0} - sy\big|_{x=0} - R_m \frac{dy}{dt}\Big|_{x=0} = 0$

$$-T\frac{dy}{dx}\Big|_{x=0} - sy\big|_{x=0} - R_m\frac{dy}{dt}\Big|_{x=0} = 0$$

drop $e^{+j\omega t}$ from remaining calculations since it cancels out

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(iv) substitute solution into b.c.'s

$$+jkT - jkTB - s - sB - j\omega R_m - j\omega R_m B = 0$$

$$B = \frac{jkT - s - j\omega R_m}{jkT + s + j\omega R_m}$$

$$= \frac{j\omega}{j\omega}\,\frac{\frac{k}{\omega}T + j\frac{s}{\omega} - R_m}{\frac{k}{\omega}T - j\frac{s}{\omega} + R_m} \qquad k = \frac{\omega}{c}, \quad T = \rho_L c^2$$

$$= \frac{\rho_L c - R_m + j\frac{s}{\omega}}{\rho_L c + R_m - j\frac{s}{\omega}}$$

(v) when $R_m = \rho_L c$ and $s = 0$

then $B = 0$

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Problem 3.

A plane sound wave propagating in air has the form

$$p(x, y, z, t) = Ae^{-j(5x+7y+6z)}e^{j\omega t}$$

where A is complex. It may be assumed that the air density is 1.2 kg/m^3 and that the ambient sound speed is 340 m/s.

(i) What is the magnitude of the wave vector: i.e., the wavenumber? What is the wavelength of the sound wave? What is the frequency of the wave?

(ii) Specify the angle of propagation of the wave in terms of the polar angle, θ, and the azimuth angle, φ.

(iii) Derive an expression for the y-component of the particle velocity, and then the y-component of the intensity.

25
49
36
110

$$p(x,y,z,t) = A e^{-i(5x+7y+6z)} e^{j\omega t}$$

$$\rho_0 = 1.2\ \text{kg/m}^3 \qquad c = 340\ \text{m/s}$$

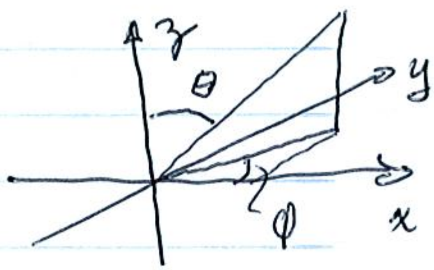
(i) $|\bar{k}_v| = \sqrt{5^2+7^2+6^2} = 10.5$ rad/m

$$k = \frac{2\pi}{\lambda} \Rightarrow \lambda = \frac{2\pi}{k} = \frac{2\pi}{10.5} = 0.598\ \text{m}$$

$$k = \frac{\omega}{c} \Rightarrow \omega = ck = 340 \cdot 10.5 = 3570\ \cancel{\text{Hz}}\ \frac{\text{rad}}{\text{s}}$$

$$= 568\ \text{Hz}$$

(ii)



$$k_z = k\cos\theta$$

$$\cos\theta = \frac{k_z}{k} = \frac{6}{10.5} = 0.571$$

$$\theta = 55.1^\circ = 0.963\ \text{rad}$$

$$k_x = k\sin\theta\cos\phi$$

$$\cos\phi = \frac{k_x}{k\sin\theta} = \frac{5}{10.5(0.82)} = 0.581$$

$$\phi = 54.5^\circ = 0.951\ \text{rad}$$

(iii) $u_y = -\frac{1}{j\omega\rho_0}\frac{\partial p}{\partial y} = +\frac{1}{j\omega\rho_0}\left(+j7Ae^{-i(5x+7y+6z)}e^{j\omega t}\right)$

$$= \frac{7A}{\omega\rho_0} e^{-i(5x+7y+6z)} e^{j\omega t}$$

$$= 1.63\times10^{-3} A e^{-i(5x+7y+6z)} e^{j\omega t}\ \text{m/s}$$

$$I_y = \frac{1}{2} Re\{ p u_y^* \}$$

$$= \frac{1}{2} Re\left\{ A e^{-i(5x+7y+6z)} e^{j\omega t} \left(\frac{7A^*}{\omega \rho_0} e^{+i(5x+7y+6z)} e^{-j\omega t} \right) \right\}$$

$$= \frac{1}{2} Re\left\{ \frac{7|A|^2}{\omega \rho_0} \right\}$$

$$= \frac{3.5|A|^2}{\omega \rho_0}$$

$$= (8.2 \times 10^{-4})|A|^2 \quad W/m^2$$