ME413 Mid-Term

Benjamin Masters

TOTAL POINTS

95 / 100

QUESTION 1

1 17 / 20

- **0 pts** Correct
- ✓ - **1 pts** **Click here to replace this description.**
- ✓ - **2 pts** **Click here to replace this description.**
- **4 pts** Click here to replace this description.
- **8 pts** jjj
- **0 pts** Click here to replace this description.

QUESTION 2

2 25 / 25

- ✓ - **0 pts** **Correct**
- **1 pts** Click here to replace this description.
- **2 pts** __
- **4 pts** Click here to replace this description.
- **8 pts** Click here to replace this description.

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- **0 pts** Click here to replace this description.

QUESTION 3

3 23 / 25

- **0 pts** Correct
- **1 pts** Click here to replace this description.
- ✓ - **2 pts** **Click here to replace this description.**
- **4 pts** Click here to replace this description.
- **8 pts** Click here to replace this description.
- **16 pts** Click here to replace this description.

QUESTION 4

4 30 / 30

- ✓ - **0 pts** **Correct**
- **1 pts** Click here to replace this description.
- **2 pts** Click here to replace this description.
- **4 pts** Click here to replace this description.
- **8 pts** Click here to replace this description.
- **16 pts** Click here to replace this description.
- **0 pts** Click here to replace this description.

Benjamin Masters

School of Mechanical Engineering
Purdue University
time
ME 41300 - NOISE CONTROL

SPRING 2021

Date: Tuesday, 21 March 2021
Time: 6:00 pm – 8:00 pm
Place: Room LILY G126

INSTRUCTIONS

Begin each problem in the space provided on the examination sheets. If additional space is required, use the paper provided to you. Work on one side of each sheet only, with only one problem on a sheet.

This is a closed book, closed note examination. Please remember that for you to obtain maximum credit for a problem, it must be clearly presented, i.e.

- the coordinate system must be clearly identified.
- units must be clearly stated as part of the answer.

If the solution does not follow a logical thought process, it will be assumed in error.

Problem 1: ____________________ /20

Problem 2: ____________________ /25

Problem 3: ____________________ /25

Problem 4: ____________________ /30

Total: ____________________ / 100

Problem 1

(i) What is the sound? **(2 points)**

Sound is the resulting propagation from the disturbance of an equilibrium state.

(ii) For a system to oscillate it must possess Mass and Spring (inertia and stiffness) **(2 points)**

(iii) The acoustic pressure $p = \hat{p}(x)e^{j\omega t}$ where $\hat{p}(x)$ is complex.

The real part of the solution corresponds to the physically measurable pressure. or magnitude? **(2 points)**

(iv) A force $Fe^{i\omega_1 t} = Ae^{i\omega t}$ is applied to a linear SDOF system having a natural frequency ω_0. At what frequency does the system respond? **(2 points)**

System responds related to ω_1 where $r = \frac{\omega_1}{\omega_0}$ and r is related to ξ (damping coefficient).

-1

(v) When sound is transmitted along a pipe with a constant diameter, what is the required boundary condition for an open tube? **(2 points)**

$P_{exit} = P_{ambient}$, $u(0) = 0$

(vi) In linear acoustics, how does the acoustic (fluctuating) pressure, p' is related to fluctuating density, ρ' at a point? **(2 points)**

As pressure increases, density increases as well.
related by speed of sound.
$p' = \rho' \cdot c$

$p' = \rho' c_0^2$

(vii) Explain the difference between nodes and anti-nodes in a standing wave. **(2 points)**

nodes are locations of zero pressure, anti-nodes are locations of maximum pressure.

(viii) How does speed of sound depend on temperature? **(2 points)**

The speed of sound slightly increases with temperature.

$\propto \sqrt{T}$

-1

(ix) At any given point in an ideal fluid, the sound pressure and particle velocity is small in all directions. Since pressure is the same in all direction at a point, we can say that the pressure

is a ~~complex~~ scalar quantity but particle velocity is a ~~real~~ vector quantity.

-1

(x) How can the acoustic intensity be used to determine the sound power of a source? **(2 points)**

$P = I \cdot A$
(power) (intensity) $\cdot$ (Area)

Problem 2 (25 points)

(a) An accelerometer indicates that the acceleration of a body is sinusoidal at a frequency of 30 Hz with the maximum acceleration of 65 m s^{-2}. What are the amplitude of the displacement and the maximum velocity of the body?

(b) The algebraic sum of two harmonic motions x_1 and x_2 is given by

$$\begin{aligned} x &= x_1 + x_2 \\ &= A\cos(\omega t + \theta) \end{aligned}$$

where $x_1 = 2\sin(\omega t - \pi/3)$, $x_2 = -3\cos(\omega t + 3\pi/4)$ and ω is the angular speed of the harmonic motions. Draw x_1 and x_2 on a phasor diagram and represent them by complex notations. Hence, or otherwise, find the magnitude, A and the phase, θ of x.

(c) If the two parallel surfaces of a room are separated by 10 m, determine the lowest frequency for resonating standing waves that exist between the surfaces.

(d) A mud reconditioning degasser is operated on a **hard** ground surface. At a distance of 5 m, the total sound pressure level, L_T, is measured to be 72 dB in the presence of a background noise level of 68 dB.

(i) What is the sound pressure level of the degasser, L_p, if there is no background noise?

(ii) What is the sound power level of the degasser, L_w?

Some useful formulas are given below:

$$c_0 = f\lambda,\ k = \omega/c_0\ ,\ \omega = 2\pi f,$$

$$\textit{Free field: } L_p = L_W - 11 - 20\log r$$

$$\textit{Above a hard ground: } L_p = L_W - 8 - 20\log r$$

$\frac{\pi}{2} + \frac{\pi}{3} \Rightarrow \frac{3\pi}{6} + \frac{2\pi}{6} = 5\pi/6$

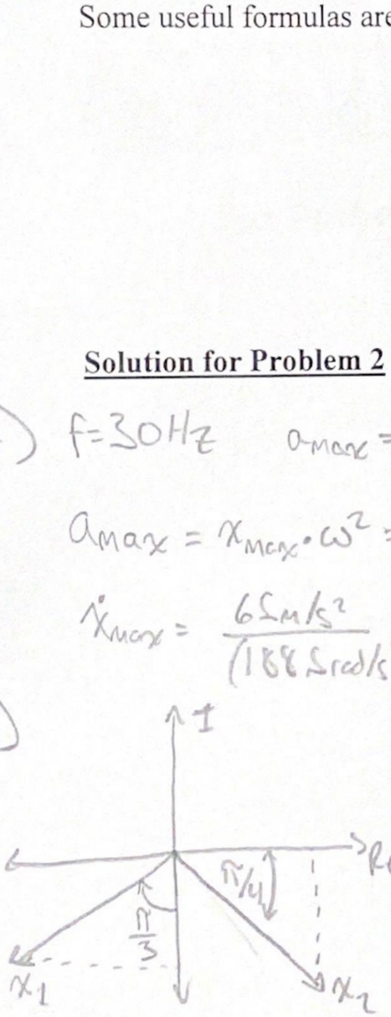
Solution for Problem 2

a) $f = 30\,Hz$ $\quad a_{max} = 65\,m/s^2$ $\quad \omega = 2\pi f = 2\pi \cdot 30\,Hz = \omega = 188.5\,rad/s$

$a_{max} = x_{max} \cdot \omega^2 = \dot{x}_{max} \cdot \omega$ $\quad x_{max} = \frac{65\,m/s^2}{(188.5\,rad/s)^2} = \boxed{1.8\,mm = x_{max}}$ or $= .0018\,m = x_{max}$

$\dot{x}_{max} = \frac{65\,m/s^2}{(188.5\,rad/s)} = \boxed{0.345\,m/s = \dot{x}_{max}}$

b)



x_1: $Re[x_1] = \sin(\pi/3) \cdot 2 = -1.73$
$I[x_1] = \cos(\pi/3) \cdot 2 = -1$ $\quad \boxed{x_1 = 2e^{-(5\pi/6)i}}$

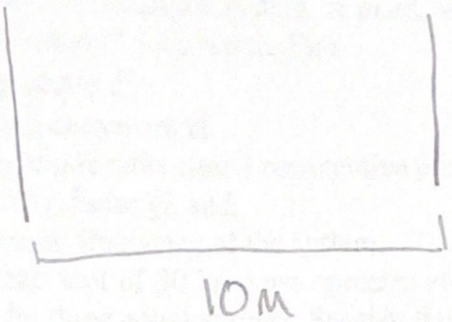
x_2: $Re[x_2] = \cos(\pi/4) \cdot 3 = 2.12$
$I[x_2] = \sin(\pi/4) \cdot 3 = -2.12$ $\quad \boxed{x_2 = 3e^{-(\pi/4)i}}$

x: $Re[x] = Re[x_1] + Re[x_2] = 2.12 - 1.73 = 0.39$
$I[x] = I[x_1] + I[x_2] = -2.12 - 1 = -3.12$

$|A| = \sqrt{.39^2 + 3.12^2} = \boxed{3.14 = A}$ $\quad \theta = \tan^{-1}(-3.12/.39) = \boxed{-1.45\,rad = \theta}$ $\quad \boxed{x = 3.14e^{-1.45i}}$

Solution for Problem 2

c)



$f_n = ?$ $\quad f_n\lambda = c_o = \frac{f_n}{2L}$

$$f_n = \frac{c_o}{2L} = \frac{343 m/s}{20 m} = \boxed{17.15 Hz = f_n}$$

d) hard ground... $r = 5m$ $\quad L_T = 72 dB$ $\quad L_{Bg} = 68 dB$

$$P_T = 10^{72/20} \cdot 20\times10^{-6} Pa = .0796 Pa$$

$$P_{Bg} = 10^{68/20} \cdot 20\times10^{-6} Pa = .0502 Pa$$

$$P_d^2 = P_T^2 - P_{Bg}^2 = .00382 \qquad L_d = 10 \log\left(\frac{.00382}{(20\times10^{-6})^2}\right) = 69.8 dB = L_d$$

(i) $\boxed{L_{p,d} = 69.8 dB}$ $\qquad L_{p,d} = L_w - 8 - 20 \log(r)$

$$L_w = L_{p,d} + 8 + 20 \log(r) \Rightarrow L_w = 69.8 dB + 8 dB + 20 \log(5)$$

(ii) $\boxed{L_w = 91.78 dB}$

Problem 3 (25 points)

(a) For a spring-mass-dashpot system, if mass, $m = 7$ kg, spring stiffness, $k = 6$ kN/m and the damping constant $C = 35$ N s/m, find

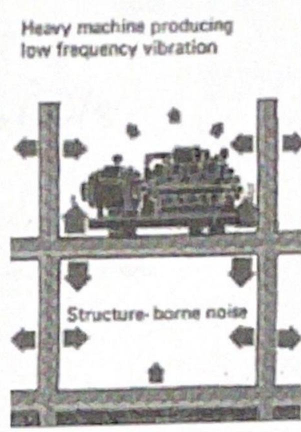
(i) damping factor ξ,

(ii) logarithm decrement δ,

(iii) the amplitude ratio after 3 consecutive cycles,

(iv) the quality factor Q, and,

(v) the resonant frequency of the system.



(b) A refrigerator unit of 30 kg mass operates at 700 rpm. The unit is supported by three equal springs. Specify the springs if 10 percent or less of the unbalance force is transmitted to the foundation.

(c) A heavy machinery is placed in a concrete building (with low internal damping) as shown in the diagram. Suggest a practical measure that can be used to reduce the structure borne noise.

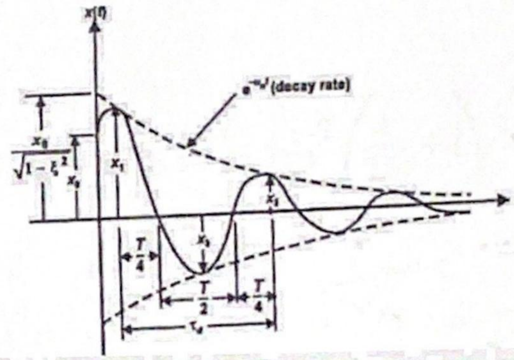
Useful formulas:

(i) Free vibration:

$$m\ddot{X}(t) + C\dot{X}(t) + kX(t) = 0$$

That can also be written as

$$\ddot{X}(t) + 2\xi\omega_n\dot{X}(t) + \omega_n^2 X(t) = 0$$



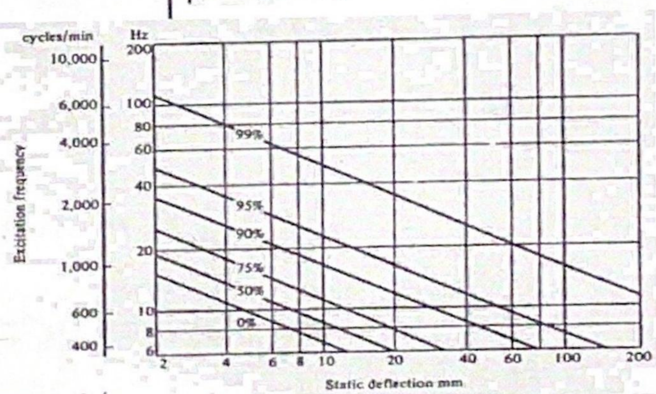
$$\delta = \ln\left(\frac{x_1}{x_2}\right) = \frac{2\pi\xi}{\sqrt{1-\xi^2}}$$

$B.W. = 2\xi$; $Q = 1/B.W. = 1/2\xi$

$$TR = \frac{1}{\frac{(2\pi f)^2 \delta_{st}}{g} - 1}$$

$$\frac{C}{m} = 2\xi\sqrt{k/m}$$

$$C = 2\xi\sqrt{k \cdot m}$$



Solution for Problem 3

a) $m = 7kg$ $k = 6kN/m = 6000N/m$ $C = 35N\text{-}s/m$

$\xi = \frac{C}{C_c}$, $C_c = 2\sqrt{km} \Rightarrow \xi = \frac{C}{2\sqrt{km}} = \frac{35N\text{-}s/m}{2\sqrt{6000\frac{N}{m} \cdot 7kg}} = \boxed{\xi = .085}$ (i)

$\delta = \frac{2\pi\xi}{\sqrt{1-\xi^2}} = \frac{2\pi(.085)}{\sqrt{1-(.085)^2}} = \boxed{.536 = \delta}$ (ii) for 3 cycles: $\frac{\delta}{3} = \ln(x_1/x_3)$

-2

$\frac{x_1}{x_3} = 10^{\delta/3} = 10^{(.536/3)} = \boxed{\frac{x_1}{x_3} = 1.5}$ (iii)

$Q = 1/2 \cdot .085 = \boxed{Q = 5.88}$ (iv)

$W_n = \sqrt{k/m} = \sqrt{6000N/m / 7kg} = 29.27 rad/s$

(v) $\boxed{W_n = 29.27 rad/s \text{ or } f_n = 4.66Hz}$

Solution for Problem 3

b) $m = 30\,kg$ $f = 700\,rpm$ $K = 3k'$ $|TR| \leq .10$

$f = \frac{700\,rot}{Min} \cdot \frac{1\,min}{60\,sec} = 11.67\,Hz \Rightarrow \omega = 73.3\,rad/s$

$\omega_n = \sqrt{k/m}$ $r = \frac{\omega}{\omega_n}$ ① $\sqrt{g/\delta_{st}} = \omega_n = \sqrt{k/m}$

$TR = \frac{1}{(2\pi f)^2 \cdot \frac{\delta_{st}}{g} - 1} \Rightarrow \frac{\delta_{st}}{g} = \frac{1}{\omega_n^2}$ $(2\pi f)^2 = \omega^2$

$TR = \frac{1}{\frac{\omega^2}{\omega_n^2} - 1} \Rightarrow \frac{1}{TR} = \frac{\omega^2}{\omega_n^2} - 1 \Rightarrow \omega^2 = \omega_n^2\left(\frac{1}{TR} + 1\right)$

$\omega^2 = \omega_n^2\left(\frac{1}{.10} + 1\right) \Rightarrow 11\omega_n^2 = \omega^2$ $\omega_n^2 = \frac{\omega^2}{11} \Rightarrow \omega_n = \sqrt{\omega^2/11} = \frac{\omega}{\sqrt{11}}$

$\omega_n = \frac{73.3\,rad/s}{\sqrt{11}} = 22.1\,rads$ $\omega_n = \sqrt{k/m}$ $k = \omega_n^2 \cdot m$

$k = (22.1\,rad/s)^2 \cdot 30\,kg = 14652.3\,N/m = 14.65\,kN/m$

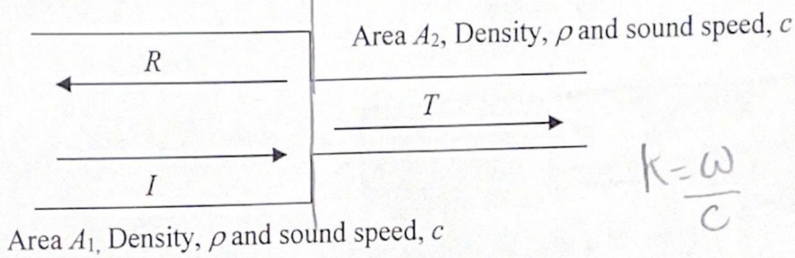
$k' = k/3 \Rightarrow k' = 14.65\,kN/m / 3 \Rightarrow \boxed{k' = 4.88\,kN/m}$ (Stiffness of each spring)

c) One method to reduce structure born noise is to drive the pillars the machine is mounted on directly into the ground, instead of bolting it to the concrete floor. Another method could be to isolate the machine from the structure with springs.

Problem 4 (30 points)

Two pipes of cross-sectional area A_1 and A_2 contain fluid media of the same density (ρ) and the speed of sound (c). The pipes are connected as shown in the following diagram. Plane acoustic disturbances are transmitted from the inlet pipe A_1 to the outlet pipe A_2. Suppose that the amplitudes of the incident wave, the reflected wave, R and the transmitted wave are I, R and T respectively.

$x = 0$



$k = \frac{\omega}{c}$

Diagram showing two connecting pipes.

Choose x as the coordinate along the pipes and take $x = 0$ at the junction of the two pipes

(a) What are the acoustic pressure and particle velocity at the inlet region ($x < 0$)?

(b) Similar, write down the acoustic pressure and particle velocity at the outlet region ($x > 0$).

(c) What are the required boundary conditions for the acoustic disturbances transmitted through and reflected from the junction?

(d) Show that the amplitudes of the reflected and transmitted waves (R and T) are related to I (amplitude of the incident wave) by

$$\frac{R}{I} = \frac{A_1 - A_2}{A_1 + A_2} \quad \text{and} \quad \frac{T}{I} = \frac{2A_1}{A_1 + A_2}$$

(e) Show that the transmission loss L_T of the acoustic pressure through the junction is given by

$$L_T = 10\log\left[\frac{(A_1 + A_2)^2}{4A_1A_2}\right]$$

(Hint: $L_T = 10 \log_{10}$ [Incident Power/Transmitted Power])

(f) Suppose that $A_1 = 1.2$ m^2 and $A_2 = 0.8$ m^2, find the transmission loss of the acoustic pressure. You may assume that $\rho = 1.2$ kg m^{-3} and $c = 340$ m s^{-1}.

(g) At the inlet pipe, the pressure has an amplitude of 5.0×10^{-3} Pa,. What is the sound pressure level and the amplitude at the outlet pipe?

Useful Equations:

1-d Helmholtz equation: $\boxed{\frac{d^2p}{dx^2} + k^2p = 0}$ Solution: $p(x, \omega) = Ae^{-ikx} + Be^{ikx}$

$L_p = 10\log\left(p_{rms}^2 / p_{ref}^2\right)$ with p_{ref}, as 2×10^{-5} pa.

Solution for Problem 4

a) $p(x) = Ae^{-ikx} + Be^{ikx} = \boxed{Ie^{-ikx} + Re^{ikx} = p(x, x<0)}$ ✓

$u(x) = \frac{1}{\rho_0 c_0}\left[Ae^{-ikx} - Be^{ikx}\right] = \boxed{\frac{1}{\rho_0 c_0}\left[Ie^{-ikx} - Re^{ikx}\right] = u(x, x<0)}$ ✓

b) $p(x) = Ae^{-ikx} + Be^{ikx} \Rightarrow \boxed{p(x, x>0) = Te^{-ikx}}$ ✓

$u(x) = \frac{1}{\rho_0 c_0}\left[Ae^{-ikx} - Be^{ikx}\right] \Rightarrow \boxed{u(x, x>0) = \frac{T}{\rho_0 c_0} e^{-ikx}}$ ✓

c) pressure equal at $x=0$ $\Rightarrow T = I + R \Rightarrow R = T - I$ ✓

$A_1 u_1(x) = A_2 u_2(x)$ $\quad \frac{A_1}{A_2} = \frac{T}{I - R}$ ② $\Rightarrow A_1(I-R) = A_2 \cdot T$ ✓

d) $A_1 I - A_1 R = A_2 I + A_2 R \Rightarrow (A_1 - A_2) I = (A_1 + A_2) R$

$\boxed{\frac{R}{I} = \frac{A_1 - A_2}{A_1 + A_2}}$ and $A_2 T = A_1 I - A_1(T - I)$

$A_2 T = A_1 I + A_1 I - A_1 T$

$(A_2 + A_1) T = 2 A_1 I$ ✓

$\boxed{\frac{T}{I} = \frac{2A_1}{A_1 + A_2}}$

Excellent

e) transmission loss $= (I/T)^2 = \frac{(A_1 + A_2)^2}{4A_1} \cdot \frac{1}{A_2}$ $\quad$ knowing Power $= I \cdot A$ and $I = \frac{p^2}{\rho_0 c_0}$

so $L_T = 10 \log\left((A_1 + A_2)^2 / 4A_1^2\right)$

f) $L_T = 10 \log\left((A_1 + A_2)^2 / 4A_1 A_2\right) = 10 \log\left((2)^2 / (4 \cdot 1.2 \cdot .8)\right) = \boxed{0.177 = L_T}$ ✓

g) $P_{loss} = 10^{.177/20} \cdot 20 \times 10^{-6} = 2 \times 10^{-5}$ $\quad p^2 = (5 \times 10^{-3})^2 - (2 \times 10^{-5})^2 \, Pa = 2.5 \times 10^{-5}$

$\boxed{P = 4.99 \times 10^{-3} \, Pa}$ ✓ $\quad L_{P,T} = 20 \log\left(4.98 \times 10^{-3} / 20 \times 10^{-6}\right) = \boxed{47.93 \, dB = L_{P,T}}$ ✓