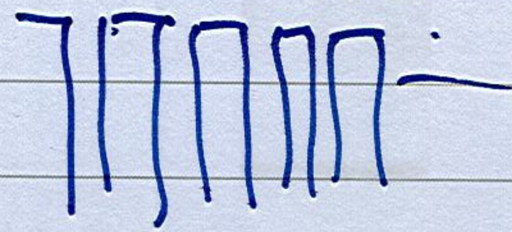
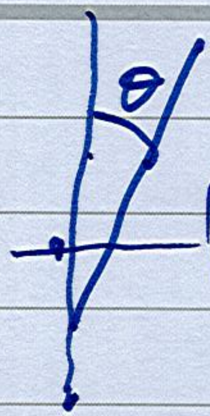
MR 513 Session 44 12/11/15



2013 (5)



$$p(r) = \frac{A_1}{r_1} e^{-jkr_1} e^{j\phi} + \frac{A_2}{r_2} e^{-jkr_2}$$

$$A \left\{ \frac{e^{j\phi} e^{-jk(r-\Delta)}}{r-\Delta} - \frac{e^{-jk(r+\Delta)}}{r+\Delta} \right\}$$

$$k\Delta = \frac{ks\cos\theta}{2}$$

$$A e^{j\phi/2} \left\{ e^{+j\frac{\phi}{2}} \ldots - e^{-j\frac{\phi}{2}} \ldots \right\}$$

$$= A e^{j\frac{\phi}{2}} e^{-jkr} \left\{ \frac{(r+\Delta) e^{j(k\Delta + \frac{\phi}{2})} - (r-\Delta) e^{-j(k\Delta + \frac{\phi}{2})}}{r^2 - \cancel{\Delta^2}} \right\}$$

$$= A e^{j\frac{\phi}{2}} e^{-jkr} \left\{ \frac{\cancel{r}\left(e^{j(k\Delta + \frac{\phi}{2})} - e^{-j(k\Delta + \frac{\phi}{2})}\right)}{r^{\cancel{2}}} \right\}$$

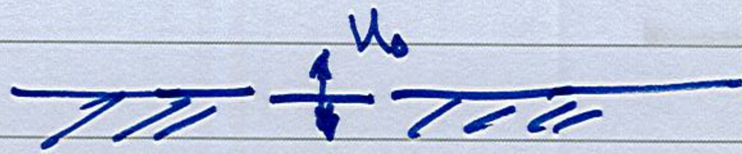
$$= A e^{j\frac{\phi}{2}} \frac{e^{-jkr}}{r} 2j \sin(k\Delta + \phi/2)$$

$$k\Delta + \frac{\Phi}{2} = 0$$

$$k\frac{\check{s}}{2}\cos^{2}\theta + \frac{\Phi}{2} = 0$$

· 90

2007 (3)
2009 (6)



$a = 0.05\,m$

$c = f\lambda$ $\qquad$ $ka \ll 1$

$\lambda = \frac{c}{f} = \frac{340}{100} = 3.40m$ $\qquad$ $\frac{a}{\lambda} \ll 1$

$\frac{1}{20 \times 3.4}$

monopole on a hard surface.

$\tilde{p}(r) = j\rho_0 c k Q \frac{e^{-jkr}}{2\pi r}$ $\qquad$ $u_0(\pi a^2)$

$L_p = 90 \text{ dB re } 20\mu Pa$

$$= 10\log_{10}\frac{p_{rms}^2}{p_{ref}^2} \Rightarrow \underline{\underline{p_{rms}^2}} = \underline{\underline{p_{ref}^2\, 10^{L_p/10}}}$$

9

$$p_{rms}^2 = \frac{\hat{p}\hat{p}^*}{2} = \frac{j\rho_0 ck Q \frac{e^{-jkr}}{2\pi r}}{2}\left(-j\rho_0 ck \frac{Q^*}{2\pi r} e^{+jkr}\right)$$

$$= \frac{|Q|^2}{2}\left(\frac{\rho_0 c k}{2\pi r}\right)^2$$

$$p_{ref}^2\, 10^9 = \frac{|Q|^2}{2} \Big/ \left(\frac{\rho_0 c k}{2\pi r}\right)^2 \qquad k = \frac{\omega}{c} = \frac{2\pi 100}{340}$$

solve for

2m

$$|Q| = |u_0|(\pi a^2) \rightarrow |u_0|$$

$$u_0 = j\omega \xi$$

$$|u_0| = \omega |\xi|$$

$$|\xi| = \frac{|u_0|}{\omega}$$

(ii) $$\overline{\Pi} = \frac{|u_0|^2}{2} R_r$$

<u>$ka \ll 1$</u>

$$R_r \simeq \frac{\pi a^2}{2} \rho_0 c (ka)^2$$

Name: ______________________________

ME 513

Final Exam – Fall 2013 --- 12/10/2013

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, and the text (Kinsler, Frey, Coppens and Sanders) or to any other acoustics text

- Problem 1: __________/30
- Problem 2: __________/20
- Problem 3: __________/20
- Problem 4: __________/20
- Problem 5: __________/20
- Problem 6: __________/20

Problem 1. (30 points)

(i) What is sound?

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

(iii) When a SDOF system is driven at frequencies well below its natural frequency, its response is controlled by ____.

(iv) How does a pulse propagating along a tensioned string reflect from a rigid termination?

upside down + backwards

(v) How does the sound pressure magnitude vary with radius in the farfield of a cylindrical source?

(vi) The ratio of pressure to particle velocity for a freely propagating plane wave is said to be the ____.

(vii) At the interface between two ideal fluids, which component of the acoustic particle velocity is continuous across the interface? Why?

(viii) Pressure continuity at the interface of two fluids is required to prevent ____ .

(ix) When considering sound transmission through a limp barrier, doubling either the ____________________ or the ______________________ causes the transmission loss of the barrier to increase by 6 dB.

(x) What physical features can make a reflecting surface "locally reacting"?

channels drilled into the surface

(xi) A dipole can be used to represent a source that exhibits no ___volume change___ but which exerts a ___force___________________ on the fluid at a point.

(xii) When a point monopole having high internal impedance is placed at the junction of two rigid, perpendicular surfaces, the sound power radiated by the source increases by a factor of _________________________ .

(xiii) Consider a square piston having a side length l and oscillatory velocity U in a rigid baffle. When l is very small compared to a wavelength, the piston source may be modeled as a ___monopole___ having source strength ___Ul^2___ .

Problem 5. (20 points)

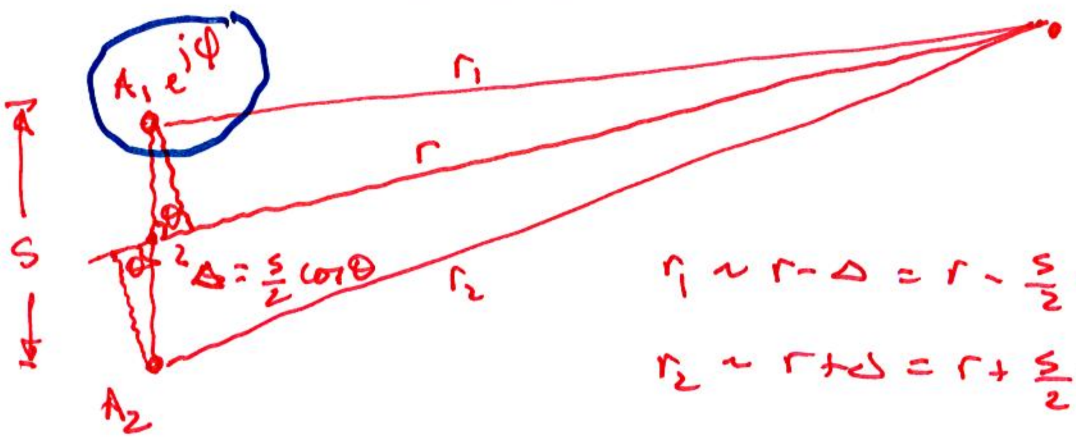
A dipole can be considered to consist of two closely-spaced monopoles of equal strength operating 180 deg. out-of-phase with each other. The sound field radiated by the dipole is zero on the surface defined by $\theta = \pi/2$, where θ is the polar angle measured from the dipole axis.

However, it may be desirable that the sound field be zero at some other polar angle.

So, imagine that the phase, φ, of the first of the two monopoles that make up the dipole is adjustable: i.e., the sound field radiated by the first monopole is

$$\frac{A}{r_1} e^{-jkr_1} e^{j\phi}$$

By following an approach similar to that used to derive the farfield of a dipole, find the value of φ that is required to make the sound radiation zero on the surface defined by $\theta = \pi/4$. Sketch the directivity of the sound field in this case.



See session 35

$$r_1 \sim r - \Delta = r - \frac{s}{2}\cos\theta$$

$$r_2 \sim r + \Delta = r + \frac{s}{2}\cos\theta$$

$$p(r) \simeq \frac{A_1}{r_1} e^{-ikr_1} e^{j\phi} + \frac{A_2}{r_2} e^{-ikr_2}$$

$A_2 = -A_1$

$$= A \left\{ \frac{e^{j\phi} e^{-ik(r-\Delta)}}{r-\Delta} - \frac{e^{-ik(r+\Delta)}}{r+\Delta} \right\}$$

$$= A e^{j\phi/2} \left\{ e^{j\phi/2} \frac{e^{-ik(r-\Delta)}}{r-\Delta} - \frac{e^{-j\frac{\phi}{2}} e^{-ik(r+\Delta)}}{r+\Delta} \right\}$$

$$= A e^{j\phi/2} e^{-jkr} \left\{ \frac{e^{j\frac{\phi}{2}} e^{jk\Delta}}{r-\Delta} - \frac{e^{-j\frac{\phi}{2}} e^{-jk\Delta}}{r+\Delta} \right\}$$

$$= A e^{j\frac{\phi}{2}} e^{-jkr} \left\{ \frac{(r+\Delta) e^{j(k\Delta+\frac{\phi}{2})} - (r-\Delta) e^{-j(k\Delta+\frac{\phi}{2})}}{r^2 \cancel{- \Delta^2}} \right\}$$

$$= A e^{j\frac{\phi}{2}} e^{-jkr} \left\{ \frac{r\left(e^{j(k\Delta+\frac{\phi}{2})} - e^{-j(k\Delta+\frac{\phi}{2})}\right) \cancel{+ \Delta\left(e^{j(k\Delta+\frac{\phi}{2})} + e^{-j(k\Delta+\frac{\phi}{2})}\right)}}{r^2} \right\}$$

$$= A e^{j\frac{\phi}{2}} \frac{e^{-jkr}}{r} 2j \sin\left(k\Delta + \frac{\phi}{2}\right)$$

want sound field = 0

$$\therefore \quad k\Delta + \frac{\phi}{2} = 0$$

$$\frac{ks}{2} \cos\theta + \frac{\phi}{2} = 0$$

$$\phi = -ks\cos\theta$$

$$\theta = \frac{\pi}{4}$$

Name: ____________________________

ME 513Q --- Engineering Acoustics

Final Exam – Fall 2007 --- 12/13/2007

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- Problem 2: ___________/20
- Problem 3: ___________/20
- Problem 4: ___________/20
- Problem 5: ___________/20
- Problem 6: ___________/20

Problem 1.

(i) What is sound?

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

(iii) When a SDOF system is driven by an external force at its natural frequency, it is said to be ______________________________________ .

(iv) Why was the reference intensity chosen to be 1×10^{-12} W/m^2?

minimum sound pressure audible by healthy young adult - so all audible SPL's are positive

(v) In the development of the wave equation for an ideal fluid, the fluid is assumed to have no ________________________ and to undergo ________________________ compression.

no reflections from bottom

(vi) When a plane wave in air hits the surface of a very deep layer of water at normal incidence, the transmitted pressure magnitude is twice than that of the incident wave while the transmitted intensity is much smaller than that of the incident wave.

(vii) When considering sound transmission through a limp barrier, doubling either the ______________________ or the ________________________ causes the transmission loss of the barrier to increase by 6 dB.

(viii) A "Level" has the units of ______________________________________ .

(ix) A small axial fan can be modeled as a __________________________ .

(x) When a point monopole is placed at the junction of three rigid, perpendicular surfaces, __________________ image sources are required to satisfy the hard wall boundary conditions.

(xi) Does a point monopole possess a "velocity nearfield"?

yes component $\propto \frac{1}{r^2}$

(xii) In a public address system, why is it normal to use many high frequency drivers, and a relatively small number of low frequency drivers?

(xiii) The first plane wave resonance of an open-ended tube occurs when the tube is approximately what fraction of a wavelength long?

(xiv) For a uniform piston that is large compared to wavelength and which is mounted in an infinite baffle, sketch the complete characteristics of the on-axis sound pressure magnitude as a function of distance from the center of the piston.

(xv) Acoustic loading of a loudspeaker usually causes the natural frequency of the loudspeaker to be reduced.

Problem 3.

A thin limp membrane having mass per unit area m_s is positioned a distance L above a rigid surface as shown in the sketch below. A plane wave strikes the membrane at normal incidence.

(i) Give the appropriate assumed solutions form for the sound field in the region between the membrane and the rigid backing.

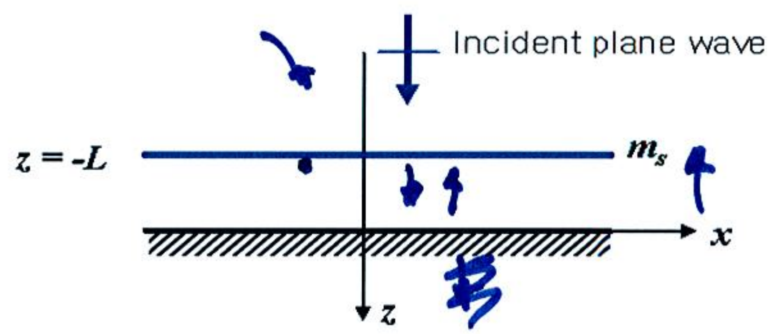
(ii) By using the linearized Euler equation, derive an expression for the particle velocity in the region between the rigid backing and the membrane.

(iii) Apply the appropriate boundary condition at the rigid backing surface, and give a solution for the sound field between the rigid backing and the membrane in terms of a trigonometric function.

(iv) Calculate the normal specific acoustic impedance, z_b, on the positive-z-facing side of the membrane: i.e., at $z = -L^+$.

(v) Calculate the total normal specific acoustic impedance, z_t of the membrane *plus* the backing airspace:i.e., find the impedance on the negative-z-facing side of the membrane at $z = -L^-$.

(vi) For the case $kL \ll 1$, find an approximate expression for the resonance frequency of this system.



(i) $p = (Ae^{-jkz} + Be^{+jkz})e^{j\omega t}$

(ii) $u_z = -\frac{1}{j\omega\rho_0}\frac{\partial p}{\partial z} = -\frac{1}{j\omega\rho_0}(-jkAe^{-jkz} + jkBe^{+jkz})e^{j\omega t}$

$= \frac{k}{\omega\rho_0}Ae^{-jkz} - \frac{k}{\omega\rho_0}Be^{+jkz}$ $\quad k=\omega/c$

$= \frac{A}{\rho_0 c}e^{-jkz} - \frac{B}{\rho_0 c}e^{+jkz}$

(iii) at $z=0$ $\quad u_z=0$

$\frac{A}{\rho_0 c} - \frac{B}{\rho_0 c} = 0 \rightarrow B = A$

$\therefore p = A(e^{-jkz} + \cancel{B}e^{+jkz})$ $\quad u_z = -\frac{1}{j\omega\rho_0}\frac{\partial p}{\partial z}$

$= 2A\cos kz$ $\quad = -\frac{1}{j\omega\rho_0}(-2kA\sin kz)$

$u_z = \frac{2A}{j\rho_0 c}\sin kz$

$$Z_t(z=-L) = \frac{p(-L)}{u_z(-L)} = \frac{\cancel{2}A\cos(-kL)}{\frac{\cancel{2}A}{j\rho_0 c}\sin(-kL)}$$

$$= j\rho_0 c \frac{\cos(-kL)}{\sin(-kL)}$$

$$= -j\rho_0 c \frac{\cos(kL)}{\sin kL}$$

$$= -j\rho_0 c \cot kL$$

(v) Impedance of membrane

$Z_m = j\omega m_s$ mass/unit area.

$$Z_t(z=-L) = j\omega m_s - j\rho_0 c \cot kL$$

(vi) $kL \ll 1$ $\quad \cot kL \to \left(\frac{1}{kL}\right)$ $\quad \frac{\cos}{\sin}$

Resonance Im impedance $\to 0$

$$\omega m_s = \rho_0 c \cot kL$$

$$\omega m_s = \frac{\rho_0 c}{kL} = \frac{\rho_0 c^2}{\omega L}$$

$$\therefore \omega^2 = \left(\frac{\rho_0 c^2}{L m_s}\right) \qquad \sqrt{\frac{\rho_0 c^2}{L\, m_s}}$$

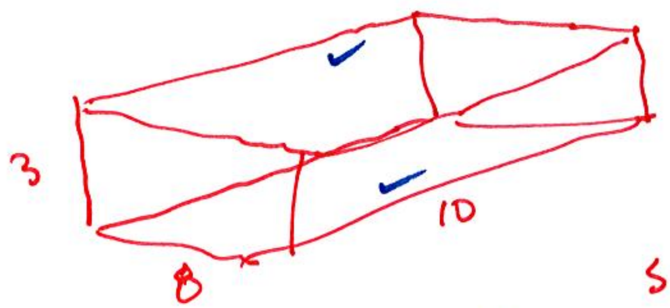
Part B (10 points)

A room is 10 m in length, 8 m wide and 3 m in height. The ceiling is covered by tiles having an absorption coefficient of 0.5 and the floor is covered by a carpet having an absorption coefficient of 0.25. The absorption at the walls may be considered negligible.

(i) What is the average Sabine absorption coefficient of the space?

(ii) What is the reverberation time in this space?

(iii) Given a source having a sound power of 1 W, what is the reverberant sound pressure level in the space?



(i)

Total surface area

$$S = 8\times3\times2 + 10\times3\times2 + 8\times10\times2 = 48 + 60 + 160 = 268\ m^2$$

$$A = \bar{a}S$$

$$S_{ceiling} = 80\ m^2$$
$$S_{floor} = 80\ m^2$$

$$\bar{a} = \frac{1}{S}\sum_i a_i S_i = \frac{1}{268}(0.5\times80 + 0.25\times80) = \frac{60}{268}$$

(ii) $$T = 0.161\frac{V}{A} = \frac{0.161\,(8\times10\times3)}{\bar{a}\,268}$$

(iii) $$p^2_{rms} = \rho_0 c\,\Pi_s\frac{4}{A} = 415(1)\times\frac{4}{\bar{a}(268)}$$

$$L_{prev} = 10\log_{10}\frac{p^2_{rms}}{p^2_{ref}} \qquad p^2_{ref} = (20\mu P)^2 = 4\times10^{-10}$$

Name: ______________________________

ME 513 --- Engineering Acoustics

Final Exam – Fall 2009 --- 12/16/2009

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- Problem 1: ____________/30
- Problem 2: ____________/20
- Problem 3: ____________/20
- Problem 4: ____________/20
- Problem 5: ____________/20
- Problem 6: ____________/20

Problem 6.

A circular rigid piston in a rigid baffle radiates into air at 100 Hz. The radius of the piston is 0.05 m.

(i) Calculate the *displacement* amplitude of the piston required to produce a sound pressure level of 90 dB re 20 μPa at a distance 2 m in front of the piston. Make use of whatever simplifying assumptions you feel appropriate under these conditions (but justify your assumptions). Comment on why a relatively large displacement amplitude is required in this case.

(ii) By using the appropriate form of the radiation impedance, calculate the sound power radiated by the piston.

(i) at 100 Hz $\lambda = 3.4$ m   radius of piston $= a = 0.05$ m

observe that $a/\lambda \ll 1$

$\therefore$ piston can be modeled as monopole on a hard surface

$$\hat{p}(r) = j \rho_0 c k Q \frac{e^{-jkr}}{2\pi r} \qquad Q = u_0 S$$

$$L_p = 10\log_{10}\frac{p_{rms}^2}{p_{ref}^2} \qquad \text{need to know } Q$$

$= 90$ at $r = 2$ m

$$\underline{p_{rms}^2} = p_{ref}^2\, 10^{90/10}$$

$$= \frac{p p^*}{2}$$

$$p_{rms}^2 = \frac{j\rho_0 c k Q}{2} \frac{e^{-jkr}}{2\pi r}\left(-j\rho_0 c k Q^* \frac{e^{+jkr}}{2\pi r}\right)$$

$$= \left(\frac{\rho_0 c k}{2\pi r}\right)^2 Q Q^* = |Q|^2\left(\frac{\rho_0 c k}{2\pi r}\right)^2$$

$$p_{ref}^2\, 10^9 = \underbrace{|Q|^2}_{\text{solve}}\left(\frac{\rho_0 c k}{2\pi r}\right)^2$$

$$|Q| = |u_0| S$$

$u_0 = j\omega \xi_0$ ← displacement

$|u_0| = \omega |\underline{\xi_0}|$

(ii) $\overline{\Pi} = \frac{|u_0|^2}{2} R_r$ radiation resistance of piston

for $ka \ll 1$

$$R_r \approx \frac{\pi a^2}{2} \rho_0 c \,(ka)^2$$