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?

(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"?

(xi) A dipole can be used to represent a source that exhibits no _____,
but which exerts a _____ 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
_____ having source strength _____ .

(xiv) Consider a piston in a rigid baffle. The radiation impedance of the piston may be used in combination with the velocity of the piston to calculate

_____ .

(xv) What is the main advantage of the two-microphone method for measuring the surface normal impedance of a sample in a plane wave tube compared to the older, probe microphone approach?

Problem 2. (20 points)

A uniformly tensioned string of finite length (tension T and mass per unit length ρ_s) is attached to a rigid support at $x = 0$. At $x = L$ the string is terminated by a point mass, m, and it is transversely constrained by a spring of stiffness s.

(i)   Give the general complex harmonic form for the transverse displacement of the string.

(ii)   Draw a free body diagram of the forces acting on the mass at $x = L$.

(iii)   Give the boundary conditions at both ends of the string.

(iv)   By applying the boundary conditions, derive the transcendental characteristic equation (written in terms of kL, where k is the wave number for transverse wave motion on the string) that could be solved to give the natural frequencies of the system.

(v)   Sketch both sides of the characteristic equation as a function of kL, and show how the natural frequencies could be located graphically.

Problem 3. (20 points)

The spatial variation for the first non-planar mode in a two-dimensional hard-walled channel of width L is:

$$p(x, y) = A_1 \cos\left(\frac{\pi y}{L}\right) e^{-jk_1 x}$$

$$where: \; k_1 = \left[k^2 - \left(\frac{\pi}{L}\right)^2 \right]^{\frac{1}{2}} \quad ,$$

$k = \omega/c$, c is the ambient sound speed, A_1 is complex, x is the dimension along the length of the duct and y is the dimension transverse to the duct axis.

(i)   Derive the vector particle velocity field by using the linearized momentum equation.
(ii)   Calculate the vector intensity field in the channel, and show, in particular, that the y-component of the intensity is always equal to zero.
(iii) Find the frequency at which the x-component of the intensity first becomes non-zero: i.e., find the frequency at which this mode begins to carry acoustic energy down the duct.

Problem 4. (20 points)

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 solution 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.

Incident plane wave

$z = -L$ ———————————— m_s

x

z
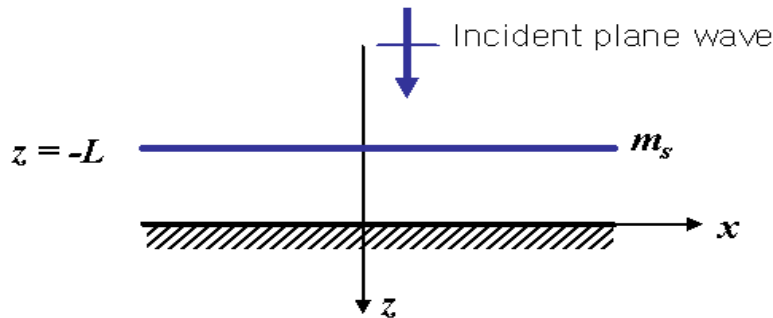
Problem 5. (20 points)

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.

Problem 6. (20 points)

A loudspeaker is placed at one end of a hard-walled duct of constant cross-sectional area S that is terminated at $x = L$ by an unflanged opening. It may be assumed that the duct radius is very small compared to a wavelength, so that a *pressure release boundary condition applies* at $x = L$. The loudspeaker diaphragm has a mass m, and its suspension has a stiffness s_d, but its damping is negligible. The delivery of a voltage to the loudspeaker voice coil causes an oscillatory force, $Fe^{j\omega t}$, to be applied to the diaphragm.

(i)   At this level of approximation, what is the termination impedance, Z_{mL}?
(ii)   Give an expression for the acoustic loading, Z_{m0}, acting on the loudspeaker in this case. Give the result in terms of kL and the total mass of air in the duct: i.e., $a = \rho_0 SL$. Note: other constants will appear in the solution.
(iii)   Give a simplified expression for Z_{m0} that is valid when $kL \ll 1$.
(iv)   Also under the condition $kL \ll 1$, give an expression for the total impedance experienced by the force acting on the loudspeaker diaphragm.
(v)   What is the natural frequency of the loudspeaker diaphragm in this case? How does it differ from the *in vacuo* natural frequency of the loudspeaker (i.e., the natural frequency of the loudspeaker if it were operated in a vacuum)?