ECE 473
Fundamentals of Engineering Acoustics

Course Goals

This course is an elective for electrical engineering, computer engineering and theoretical and applied mechanics majors. The goals are to impart the fundamentals of engineering acoustics that constitute the foundation for preparing electrical engineering, computer engineering and theoretical and applied mechanics majors to take follow-on acoustics courses.

Instructional Objectives

By completion of the course, the students should be able to do the following:

1. Calculate the displacement and velocity of a second-order mechanical system assuming simple harmonic motion with and without loss, and with and without forced harmonic excitation. (a)

2. Derive the one-dimensional wave equation for transverse waves on a string. (a)

3. Calculate the transverse wave amplitude and propagation speed from the known physical properties of a string. (a)

4. Use 3 above in reverse to design the physical properties of a string. (a, c)

5. Use the appropriate general solution of the one-dimensional wave equation of the string and solve for the transverse wave function when the string's boundary conditions are given. (a)

6. Calculate the input mechanical impedance and average input power to a string under forced harmonic excitation. (a)

7. Derive and solve the one-dimensional lossless wave equation for an acoustic wave in a fluid. (a)

8. Calculate the propagation speed in a fluid from the fluid's equation of state and from the fluid's adiabatic bulk modulus and equilibrium density. (a)

9. Use 8 above in reverse to identify the appropriate fluid. (a, c)

10. Identify the conditions under which longitudinal and shear waves can exist. (a)

11. Calculate any harmonic acoustic propagation quantity (particle displacement, particle velocity, particle acceleration, excess density, acoustic pressure, condensation, sound pressure level, temperature fluctuation) from the known fluid properties and excitation function. (a)

12. Calculate the acoustic wavelength, frequency and propagation speed when any of the two are given. (a)

13. Estimate the approximate size of a particle for a specific acoustic propagation condition in a fluid. (a)

14. Derive and solve by separation of variables the three-dimensional acoustic wave equation in a fluid. (a)

15. Calculate the acoustic pressure and particle velocity from the acoustic velocity potential. (a)

16. Calculate energy density and acoustic intensity for both a plane progressive wave and spherical progressive wave in a known fluid medium from any of the first-order propagation quanitities (particle displacement, particle velocity, particle acceleration, excess density, acoustic pressure, condensation, sound pressure level, temperature fluctuation). (a)

17. Use 16 above in reverse to calculate any of the first-order propagation quantities. (a)

18. Derive the propagation speed expression using a non-linear equation of state. (a)

19. Calculate the plane progressive wave sound pressure (SPL) values necessary to produce a fully-developed shock wave in a gas. (a)

20. Use 19 above in reverse to calculate the shock distance. (a)

21. Understand the difference between a locally-reacting and extended boundary condition. (a)

22. Derive the pressure reflection coefficient and pressure transmission coefficient using a locally-reacting boundary condition between two fluid media when the incident acoustic wave is normally incident on the boundary. (a)

23. Calculate the pressure reflection coefficient and pressure transmission coefficient between two fluid media when the incident acoustic wave is normally incident on the boundary. (a)

24. Calculate the spatial distribution of instantaneous acoustic pressure, instantaneous particle velocity and acoustic impedance in the incident fluid medium from a normally-incident reflected acoustic wave for the following boundary conditions: (a) acoustic impedance the same in both media, (b) acoustic impedance greater in the incident medium, (c) acoustic impedance less in the incident medium, (d) rigid boundary, and (e) free boundary condition. (a)

25. Calculate the locations of nodes and antinodes in a standing acoustic wave. (a)

26. Calculate the standing wave ratio (SWR) in a standing acoustic wave. (a)

27. Do 22, above when the incident acoustic wave is obliquely incident on the boundary. (a)

28. Do 23 and 24 above when the incident acoustic wave is obliquely incident on the boundary. (a)

28. Derive and apply Snell's Law using phase matching conditions. (a)

29. Use 23, 24 or 28 above to design which fluid media should be used. (a, c)

30. Derive the intensity and power reflection coefficients, and the intensity and power transmission coefficients using a locally-reacting boundary condition between two fluid media when the incident acoustic wave is both normally and obliquely incident on the boundary. (a)

31. Calculate the pressure reflection coefficient and pressure transmission coefficient between two fluid media when the incident acoustic wave is both normally and obliquely incident on the boundary. (a)

32. Identify the condition for which a critical angle and an angle of intromission exist, and calculate these angles from the fluid properties. (a)

33. Indentify the conditions for which a surface wave may exist at the boundary of two fluids, and calculate that angle from the fluid properties. (a)

34. Derive the pressure reflection coefficient and pressure transmission coefficient using a locally-reacting boundary condition when an interposed layer of known thickness exists between two media when the incident acoustic wave is normally incident on the boundary. (a)

35. Calculate the pressure reflection coefficient and pressure transmission coefficient when an interposed layer of known thickness exists between two media when the incident acoustic wave is normally incident on the boundary. (a)

36. Apply 35 above under the special condition of 100% transmission of the incident acoustic wave. (a)

37. Derive the surface displacement boundary conditions for a radially oscillating sphere in a fluid and derive the propagated acoustic field from this source. (a)

38. Calculate the strength of a source from the surface velocity and source size from which the acoustic intensity at a specified distance from the source and the total radiated acoustic power are calculated. (a)

39. Derive the far field acoustic pressure distribution for an acoustic doublet by applying the field sources from the monopole (37 above) solution. This solution models two speakers. (a)

40. Calculate the on-axis acoustic and off-axis acoustic pressure from the acoustic doublet. (a)

41. Derive the far field acoustic pressure distribution for out-of-phase line source by applying the field sources from the acoustic doublet (39 above) solution. This solution models some types of string instruments. (a)

42. Calculate the on-axis and off-axis acoustic pressure from the out-of-phase line source. (a)

43. Derive the far field acoustic pressure distribution for in-phase continuous line source by applying the field sources from the monopole (37 above) solution. This solution models some types of string instruments and demonstrates the application of a Sinc function field distribution. (a)

44. Calculate the on-axis and off-axis acoustic pressure from the in-phase continuous line source. (a)

45. Calculate the beam width and locations of the sidelobes and nulls from the in-phase continuous line source. (a)

46. Derive the near field (Fresnel) and far field (Fraunhoffer) acoustic pressure distribution for the baffled circular piston source by applying the field sources from the monopole (37 above) solution. This solution models most acoustic sources and demonstrates the application of a Bessel function field distribution. (a)

47. Calculate the on-axis and off-axis acoustic pressure from the baffled circular piston source. (a)

48. Calculate the beam width and locations of the sidelobes and nulls from the baffled circular piston source. (a)

49. Derive the far field acoustic pressure distribution for the linear array by applying the field sources from the monopole (37 above) solution. This solution models advanced loud speaker systems and sonar and other array sources and introduces grating lobes. (a)

50. Calculate the on-axis and off-axis acoustic pressure from the linear array source. (a)

51. Calculate the beam width and locations of the sidelobes, nulls and grating lobes from the linear array source. (a)

52. Derive the radiation impedance function of a baffled circular piston source. (a)

53. Calculate the radiation impedance, when both the transmitted field and the source mechanical properties are considered, of a baffled circular piston source, and calculate the resonant frequency for this system. (a)

54. Calculate total acoustic power from the radiation impedance function and the surface velocity of a baffled circular piston source. (a)

55. Use 53 and 54 above to design a baffled circular piston source. (a, c)

56. Calculate the pressure reflection coefficient and pressure transmission coefficient in a pipe (confined transmission path where acoustic wavelength is large compared to the pipe cross-sectional dimension) using the principles of 22 and 23 above. This solution models noise propagation in air delivery vents. (a)

57. Calculate the intensity reflection coefficient and intensity transmission coefficient in a pipe (confined transmission path where acoustic wavelength is large compared to the pipe cross-sectional dimension) using the principles of 30 and 31 above. This solution models noise propagation in air delivery vents. (a)

58. Calculate the resonant frequency in a pipe which has either a rigid or open end, and calculate the total acoustic power radiated under the open-pipe condition. (a)

59. Calculate the intensity reflection coefficient and intensity transmission coefficient in a pipe that has a side branch using the principles of 57 above. This solution models many wind instruments. (a)

60. Derive the acoustic radiation impedance function of a Helmholtz resonator. (a)

61. Derive an acoustic filter by using the Helmholtz resonator (60 above) as the side branch (59 above). This solution models high-pass, band-pass and low-pass acoustic filters. (a)

62. Design acoustic filters based on 61 above from the desired spectrum. (a, c)

63. Derive the acoustic propagation through a tapered exponential pipe. This solution models the impedance matching for wind instruments. (a)

64. Design a matching system based on 61 above from the desired spectrum. (a, c)

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