Winter 2011 ME-366

DESIGN OF ENGINEERED MULTIFUNCTIONAL DEVICES AND METAMATERIALS

Tues. and Thur. (9:30 a.m. – 11:00 a.m.)

Professor Wing Kam Liu

Department of Mechanical Engineering (Tech A326 x 1-7094)

Prerequisites: ME-365 or CE-327 (or equivalent)

The scope of the course is to provide the analytical and computational tools necessary for the design of complex structural and material systems for modern engineering applications, ranging from structural engineering to micro and nanotechnology. Special attention is devoted to the design of devices for vibration isolation and wave filtering and multifunctional metamaterials for energy conversion. The course is directed towards a diverse audience including senior undergraduate and graduate students of civil and mechanical engineering, materials science and applied mathematics.

1. REVIEW OF FINITE ELEMENTS FOR LATTICE STRUCTURES (weeks 1-2)

A review of finite element techniques for cellular and frame-like structures is given. The commercial software ANSYS is introduced to study the dynamic behavior of structures with complex geometry.

1.1. Truss and Frame-like Structures

1.1.1. Modeling of cellular materials and lattices as trusses and frames.
Bar elements. Euler-Bernoulli and Timoshenko beam elements.

1.1.2. Bars and beams of arbitrary orientation. Trusses and frames

Reading assignment. Stiffness, mass matrices. Boundary conditions. Assembly procedures.

1.2. Introduction to mechanical analysis with ANSYS

1.2.1. Mechanical analysis with ANSYS. Sample frame problem using GUI
Reading assignment: Online ANSYS Primer

1.2.2. Mechanical analysis with ANSYS. Sample frame problem using command files
Reading assignment: Online ANSYS tutorials

Project I – Part 1: Investigate the deformation and the internal stress state of a 2D honeycomb structure under static and harmonic loading conditions (ANSYS)

2. DESIGN OF MULTIFUNCTIONAL DEVICES (weeks 3-5)

An introduction to multi-body dynamics and mechanical vibrations is given via simple discrete systems and frame structures illustrations. The design of tunable dynamic dampers is addressed.

2.1. Introduction to System Dynamics

2.1.1. Single degree of freedom (SDOF) systems. Free and forced response. Bode and Nyquist plots. Modeling and design of sensors.

2.1.2. Multiple degree of freedom (MDOF) systems. Elements of modal analysis. Point and cross receptance. Damped systems.

2.2. Design of vibration absorbers and mechanical filters

2.2.1. Vibration absorbers. Frequency and time domain analysis of dynamic dampers.

2.2.2. Design of tunable dynamic dampers. Hydro-elastic dampers. Design of a three-degree-of-freedom dynamic damper.

Project I – Part 2: Design a truss-core honeycomb sandwich beam that minimizes the transmissibility in the low-frequency regime (ANSYS)

2.3. Design of Multifunctional Systems with Microstructures

2.3.1. Dynamics of periodic structures. Resonating microstructures. Phononic bandgaps and vibration absorption.

2.3.2. Honeycombs and sandwich panels. Piezoelectricity. Energy conversion and harvesting.

Reading assignments: selected papers

Project I – Part 3: Design a truss-core honeycomb device with internal resonating microstructure with energy harvesting capabilities (ANSYS+Matlab)

3. DESIGN OF SUPERLATTICES AND METAMATERIALS (weeks 6-10)

The problem of elastic wave propagation is considered. Particular attention is devoted to the phononic characteristics of one-dimensional periodic systems. A finite-element-based based unit cell technique is introduced to design lattices and metamaterials with enhanced filtering and energy conversion capabilities.

3.1. Wave propagation in one-dimensional structures

3.1.1. Elastic waves in strings and rods. Wave equation. Non-dispersive media.

3.1.2. String on elastic foundations. Dispersive vs. non-dispersive solids. Dispersion relations.

3.2. Design of one-dimensional periodic structures

3.2.1. Filtering properties of periodic structures. Dispersion curves. Phononic bandgaps.

3.2.2. Finite element based unit cell method. Design of 1D metamaterials.

3.3. Design of two-dimensional periodic structures

3.3.1. FE-based unit cell analysis. Phase constant surfaces. Phononic characteristics of honeycomb structures.

3.3.2. *Reading assignments: Selected papers*

3.3.3. Unit cell design of truss-core honeycomb sandwiches. Parametric studies.

Project I – Part 4: Use the finite element unit cell method to design a honeycomb with internal resonating microstructures that maximizes the phononic bandgap density (Matlab)

or alternatively

Project II: Design a thin panel with holes with in-plane filtering capability (ANSYS-Matlab)

3.4. Design of Metamaterials

3.4.1. Polarized piezoelectric materials. Newton-Maxwell equations.

3.4.2. Phonons vs. photons. Polariton propagation modes. Energy conversion.

Project III: Design the internal structure of a one-dimensional polarized piezoelectric superlattice that maximizes the phonon-photon coupling effect (Matlab)

Reference materials:

1. Cook, Malkins, Plesha, Witt, *Concepts and Applications of Finite Element Analysis*, Wiley, NY, 2002
2. J. Fish and T. Belytschko. *A first course in finite elements*. Wiley & Sons Ltd., West Sussex, UK, 2007.
3. Ogata, System Dynamics, Pearson Prentice Hall. NJ, 2004
4. Brillouin, Wave propagation in periodic structures, Dover, NY, 2003

Lecture notes, handouts, computer codes and references to book chapters and articles for additional reading will be provided.