University of Macau
Department of Electromechanical Engineering
MECH486 – Finite Element Techniques in Engineering
Syllabus
1st Semester 2012/2013
Part A – Course Outline

Required elective course in Electromechanical Engineering

Course description:

The Finite Element Method (FEM) is widely used in engineering design and to solve problems that are too complicated to tackle by using analytical methods. This course covers the basics of formulating problems in statics, dynamics and heat transfer into finite-element (FE) models and their subsequent solution. The use of the popular FE software programme, ANSYS, will be introduced to students. Different types of finite elements for handling different types of problems will be discussed and these elements will be derived by using a variety of approaches (direct stiffness method, principle of minimum potential energy, for example). The various types of finite elements covered in this course include: spring element, bar element, Bernoulli beam element, frame element, 3-noded and 6-noded triangular elements, 4-noded and 8-noded quadrilateral elements, axisymmetric element and plate-bending elements. Isoparametric transformation for achieving higher accuracy in components of curved boundaries will be covered. Additionally, problems involving thermal stresses, heat transfer and structural vibration and their solution by using the FEM will also be considered in this course. The advantages and disadvantages of the various finite elements will be discussed in detail such that the students will be able to make judicious choices of elements for solving specific problems. The strengths and weaknesses of the FEM will be introduced to students through comparison between using the FEM and other analytical methods (such as theory of elasticity) for solving the same problems.

Prerequisite:

None

Textbooks:

- Daryl L. Logan. A First Course in the Finite Element Method (4th ed). Thompson. 2007
- P.E. Lewis and J.P. Ward. The Finite Element Method : Principles and Applications. Addison-Wesley, 1991

References:

- Wahyu Kuntjoro. An Introduction to the Finite Element Method. 2005. McGraw-Hill
- William B. Beckford. A First Course in the Finite Element Method (2nd ed). Irwin Inc. 1994
- Singiresu S. Rao. The Finite Element Method in Engineering. Elsevier Butterworth Heinemann. 2005
- V. Ramamurti. Finite Element Method in Machine Design. Alpha Science International, 2009

Course objectives:

On completion of this course, students are expected to:

- Have an understanding on the fundamental principles of the finite element method (FEM), including the formulation of structures like trusses and beams into FE models, potential errors sources in building up a FE model and ways for reducing them, processing of FE results [e]
- Understand the various types of finite elements (bar element, beam element, etc.) and be able to select the right elements for solving engineering problems [e]
- Be able to apply the FEM to solve engineering and design problems which, when solved using other methods such as the Theory of Elasticity, would be tedious or impossible [a]
- Be able to use the FE software ANSYS for problem-solving and engineering design [c, l]

Topics covered:

1. **Introduction** – Review of statics; Basic structural vibration; Introduction to the FEM; Statically indeterminate structures; Compatibility of deformation; Boundaries conditions for structures; Formulation of problems into FE models; Examples of the application of the FEM in the various branches of engineering
2. **Fundamentals of FEM modelling** – Model discretisation; Treatment of boundaries; Use of symmetry in FEM modelling; Concept of work equivalence; Equivalent nodal forces; Shape functions; Interpolation functions; Methods for reducing errors
3. **Direct Stiffness Method** – Stiffness of structures; Direct Stiffness Method; the development of various simple finite elements (beam element, bar element, 3-noded triangular element, etc.) using the Direct Stiffness method; Criteria for constructing displacement interpolation functions
4. **Principle of Minimum Potential Energy** – Potential energy; Strain energy; Ritz method; Principle of Minimum Potential Energy; the development of different finite elements (3-noded, 6-noded elements) using this principle; Comparison of this principle and the Direct Stiffness Method for developing finite elements; Area coordinate and natural coordinate; Method of Weighted Residuals
5. **Other commonly used finite elements for solid mechanics** – Axisymmetric element; Rectangular plate-bending elements; Triangular plate bending element; Introduction to compatible finite element
6. **Heat transfer** – Review of basic heat transfer; Triangular element for heat transfer problems
7. **Thermal stresses** – Stresses due to temperature change; Thermal force matrices
8. **Basic structural vibration** – Review of structural vibration; Mode shape; Natural frequency; Modal analysis; Concentrated mass matrix; Consistent mass matrix; Decoupling of motion equations
9. **Isoparametric formulation** – The Lagrangian approach for construction of shape functions; Review of the inadequacies of the Lagrangian approach for curved elements; Introduction to subparametric, superparametric and isoparametric transformations; Coordinate transformations; Gauss Quadratures
10. **Comparison of the FEM and other method** – Basic theory of elasticity; Plane stress problems; Plane strain problems; Theory of thin plates; Strengths and weaknesses of the FEM compared with conventional methods (such as theory of elasticity) through solution of the same problems
11. **The software programme ANSYS** – Introduction to FEM modelling with a computer; Introduction to ANSYS; Preprocessing and postprocessing in FEM model building; Interpretation of results; Subtleties in improving model accuracy; Subtleties in FEM computer programming

Topic Outline:

Week No.	No. of hours	Topics
1	2	**Introduction** Review of Syllabus; Introduction to the FEM and its applications; FEM modelling of components and systems; Discretisation; Handling of boundaries and external loads
1, 2	6	**Direct stiffness method and spring element** Introduction to Direct Stiffness Method; the standard procedures for using Direct Stiffness Method for deriving element stiffness matrices; Spring element; Concept of shape functions
3	4	**Bar element and trusses** Bar element; Comparison between bar and spring elements; Application of bar element for solving trusses; Comparison between the FEM and Applied Mechanics in solving trusses
4	4	**Beam element and beams** Beam element; Equivalent nodal forces and moments; Application of beam element for solving beams; Review of shear force and bending moment diagrams; Comparison between the FEM and Mechanics of Materials in solving beams;
5	2	**Frame element** Frame element; Application of frame element for solving frames
5	2	**Other methods for deriving element stiffness matrices: Principle of minimum potential energy, Ritz method and Method of Weighted Residuals** Introduction to the Principle of Minimum Potential Energy; Ritz method; Brief introduction to the Method of Weighted Residuals; Use of the Principle of

		minimum Potential Energy for deriving element stiffness matrices; Comparison of the various methods in stiffness matrix derivation
6	4	**Introduction to basic theory of elasticity** Basic theory of elasticity in 2-dimensions; Plane-stress problems; Plane-strain problems; Derivation of equilibrium equations, geometric equations and constitutive equations for 2-dimensional problems; Understanding of the difficulty in using theory of elasticity in getting exact solution; Understanding in the reason for using the FEM
7	4	**Modelling in 2 dimensions: 3-noded and 6-noded triangular elements** Introduction to 3-noded triangular element; Use of 3-noded triangular element; Concept of constant-strain element; Limitations of the 3-noded element; Understanding in the strengths and weaknesses of adding nodes to elements; Introduction to the 6-noded triangular element; Area coordinates;
8	4	**Points to note in FEM modelling and processing of results** Points to note in model discretisation and choice of appropriate elements; Subtleties in converting external loads to equivalent nodal loads; Use of symmetry;
9	4	**ANSYS** Introduction to the FEM software ANSYS; General steps in building up an ANSYS model; Preprocessing and Postprocessing of results; Meshing of models; Use of ANSYS in solving different engineering problems and design; Subtleties and points to note in ANSYS modelling and computer programming **Laboratory session** Use of the ANSYS software programme
10	4	**Rectangular Plate element and basic theory of elasticity of thin plate** Introduction to the basic theory of elasticity for thin plates; Handling of different boundary conditions: Kirchhoff treatment; Understanding of limitations of the theory of elasticity in solving plates; Plate elements; Application of plate element for solving regular plates; Concept of incompatibility; Understanding of the rectangular plate element as an incompatible element and its comparison with other compatible elements; Implications in the use of incompatible element
11	2	**Axisymmetric problems** Introduction to axisymmetry; Introduction to the 3-noded axisymmetric triangular element; Comparison between conventional 3-noded triangular element and 3-noded axisymmetric element; Equivalent nodal loads for 3-noded axisymmetric element; Application of the axisymmetric element for solving axisymmetric problems;
11	2	**Lagrangian approach in constructing shape functions** Review of Lagrange polynomial and interpolation; Review of the standard procedures for constructing shape functions for elements having straight sides by using the Lagrangian approach
12	4	**Thermal stresses** Introduction to thermal stresses; Introduction to thermal force matrices; Application of the FEM for solving problems involving temperature changes and thermal stresses
13	4	**Isoparametric elements** Understanding of the limitations of the Lagrangian approach for elements having curved sides; Concept of coordinate transformation and parent elements; Introduction to subparametric, superparametric and isoparametric transformations, with emphasis on isoparametric transformation; Gauss quadratures
14	4	**Heat Transfer and structural vibration** Review of basic heat transfer; Derivation of the stiffness matrices for heat transfer problems; Use of the FEM for solving heat transfer problems; Vibration-related problems; Natural frequencies and mode shapes; Resonance

Contribution of course to meet the professional component:

This course prepares students to work professionally in the area of **design**

Relationship to EME program objectives and outcomes:

This course primarily contributes to Electromechanical Engineering Program outcomes that develop student abilities to:
(a) An ability to apply knowledge of mathematics and engineering
(c) An ability to design a system, component, or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability
(e) An ability to identify, formulate, and solve engineering problems;
(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
(l) An ability to use the computer/IT tools relevant to the discipline along with an understanding of their processes and limitations.

Course content:

Maths	Basic Science	Engineering Science	Engineering Design and Synthesis	Complementary Studies	Computer Studies	Total 100%
10	0	65	15	0	10	100

Person who prepared this description:

Dr. Kin Ho Lo

Part B General Course Information and Policies

1st Semester 2012/2013

Instructor: Dr. Kin Ho Lo Office: N306
Office Hour: By appointment: every afternoon during weekdays Phone: (853) 8397-4356
Email: KHLO@umac.mo

Time/Venue:

Every Tuesday, 11:30 p.m. - 13:30 p.m., U103
Every Friday, 11:30 p.m. - 13:30 p.m., N204

Assessment:

Final assessment will be determined on the basis of:
Tutorial problems and Homework: 10 %
Mid-term I and Mid – term II: 30%
Final Exam (Comprehensive): 60%

Grading System:

The credit is earned by the achievement of a grade from 'A' to 'D'; 'F' carries zero credit.

Grades are awarded according to the following system:

Letter Grades	Grade Points	Percentage
A	4.0 (Excellent)	93-100
A-	3.7 (Very good)	88-92
B+	3.3	83-87
B	3.0 (Good)	78-82
B-	2.7	73-77
C+	2.3	68-72
C	2.0 (Average)	63-67
C-	1.7	58-62
D+	1.3	53-57
D	1.0 (Pass)	50-52
F	0 (Fail)	Below 50

Comment:

The objectives of the lectures are to explain the text material and teach the use of commercially available FEM software for solving problems that are intractable otherwise. Students who wish to succeed in this course should read the handouts prior to lectures and should do independently all homework and lab assignments.

Homework Policy:

- There will be approximately 3-5 homework assignments
- Due date for each homework is about 2 weeks after its announcement
- Homework will be returned to students in about 10 days after submission

Quizzes/Mid-terms Exams:

Two mid-term exams will be held during the semester

Note:

- Attendance is strongly recommended
- Announcement of homework and dates for examinations will be made during lectures
- No make-up exam will be given unless with justifications (e.g., illness)

Appendix - Rubric for Program Outcomes

Rubric for (a)	5 (Excellent)	3 (Average)	1 (Poor)
Understand the theoretic background	Students understand theoretic background and the limitations of the respective applications.	Students have some confusion on some background or do not understand theoretic background completely	Students do not understand the background or do not study at all
Use a correct model and formulation correctly	Students choose a model correctly and properly apply correct techniques	Students choose a wrong model sometime, use a wrong formula, or a different technique	Students use a wrong model and wrong formula, or do not know how to model
Compute the problem correctly	Students use correct techniques, analyze the problems, and compute them correctly	Students sometime solve problem mistakenly using wrong techniques	Students do not know how to solve problems or use wrong techniques completely

Rubric for (c)	5 (Excellent)	3 (Average)	1 (Poor)
Design capability and design constraints	Student understands very clearly what needs to be designed and the realistic design constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.	Student understands what needs to be designed and the design constraints, but may not fully understand the limitations of the design constraints	Student does not understand what needs to be designed and the design constraints.
Process to meet desired needs	Student understands very clearly the process of the design	Student understands what the needs of the process design, but may not fully understand the limitations of the design constraints	Student does not understand the process.

Rubric for (e)	5 (Excellent)	3 (Average)	1 (Poor)
Identify applications in engineering systems	Students understand problem and can identify fundamental formulation	Students understand problem but cannot apply formulation.	Students cannot identify correct terms for engineering applications
Modeling, problem formulation and problem solving	Students choose and properly apply the correct techniques	Students model correctly but cannot select proper technique or model incorrectly but solve correctly accordingly	Students at loss as to how to solve a problem
Rubric for (l)	**5 (Excellent)**	**3 (Average)**	**1 (Poor)**
Use modern computer and software tools in engineering practice	Student uses the computer and software to correctly analyze engineering problems and/or create engineering designs, and understands the limitations of the software.	Student uses the computer and software to correctly analyze engineering problems and/or create engineering designs.	Student does not use the computer and software to correctly create engineering designs and/or does not correctly interpret the results.