Mtech_Design_2019 onwards CURRICULUM.pdf

Mtech_Thermal_2019 onwards CURRICULUM.pdf

Mtech_Design_2022 onwards CURRICULUM.pdf

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CURRICULUM

July 2019 admission onwards

APPROVED BY

BOARD OF STUDIES (BOS)
MEETING, February 20, 2019

MTech in Design Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

Dr B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY,

JALANDHAR

Phone: 0181-2690301, 02 (Ext. 2101, 2104), Fax: 0181-2690932 Website: www.nitj.ac.in

Annexure-F

DR B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY

JALANDHAR
Teaching Scheme and Syllabus
of
Regular MTech in Design Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

SCHEME OF INSTRUCTION AND DETAILED SYLLABI

MASTER OF TECHNOLOGY IN DESIGN ENGINEERING

EFFECTIVE FROM JULY, 2019 ONWARDS

Course Scheme for MTech in Design Engineering

FIRST SEMESTER				
S.No.	**Course No.**	**Subjects**	**L-T-P**	**Credit**
1.	MA-553	Computational Methods in Engineering	3-0-0	3
2.	ME-501	Continuum Mechanics	3-0-0	3
3.	ME-503	Materials in Mechanical Design	3-0-0	3
4.	ME-505	Finite Element Methods	3-0-0	3
5.	ME-XXX	Programme Elective-I	3-0-0	3
6.	ME-511	Material Selection Laboratory	0-0-3	2
7.	ME-513	Materials Fabrication and Development Laboratory	0-0-3	2
		Total	**15-0-6**	**19**

SECOND SEMESTER				
S.No.	**Course No.**	**Subjects**	**L-T-P**	**Credit**
1.	ME-502	Advanced Machine Design	3-0-0	3
2.	ME-504	System Dynamics and Control	3-0-0	3
3.	ME-506	Mechanical Vibrations	3-0-0	3
4.	ME-508	Design and Optimizations	3-0-0	3
5.	ME-XXX	Programme Elective-II	3-0-0	3
6.	ME-512	Design of Mechanical System Laboratory	0-0-3	2
7.	ME-514	Advanced Mechanical Vibration Laboratory	0-0-3	2
		Total	**15-0-6**	**19**

THIRD SEMESTER				
S.No.	**Course No.**	**Subject**	**L-T-P**	**Credit**
1.	ME-600	Project Work for M Tech Dissertation, Part-I	0-0-12	6
2.	ME-601	Independent Study	0-0-6	3
3.	ME-XXX	Programme Elective-III	3-0-0	3
4.	ME-XXX	Programme Elective-IV	3-0-0	3
		Total	**6-0-18**	**15**

FORTH SEMESTER				
S.No.	**Course No.**	**Subject**	**L-T-P**	**Credit**
1.	ME-600	Project Work for M Tech Dissertation, Part-II	0-0-24	12
		Total	**0-0-24**	**12**

Summary				
Semester	**I**	**II**	**III**	**IV**
Semester-wise total credit	**19**	**19**	**15**	**12**
Total credits	**65**			

Credit Distribution for MTech in Design Engineering					
Category	**Sem - I**	**Sem - II**	**Sem - III**	**Sem - IV**	**Total No. of Credits to be earned**
Core Courses	**9**	**9**	**-**	**-**	**18**
Electives	**6**	**6**	**6**	**-**	**18**
Lab Courses	**4**	**4**	**-**	**-**	**8**
Seminar	**-**	**-**	**3**	**-**	**3**
Dissertation	**-**	**-**	**6**	**12**	**18**
Total	**19**	**19**	**15**	**12**	**65**

Programme Electives				
S.No.	**Course code**	**Subjects**	**L-T-P**	**Credit**
1.	ME-515	Advanced Material Science	3-0-0	3
2.	ME-516	Advanced Solid Mechanics	3-0-0	3
3.	ME-517	Automotive Design	3-0-0	3
4.	ME-518	Basic Biomechanics	3-0-0	3
5.	ME-519	Computer Aided Design	3-0-0	3
6.	ME-520	Continuum Damage Mechanics	3-0-0	3
7.	ME-521	Control Theory and Applications	3-0-0	3
8.	ME-522	Design of Fluid Film Bearings	3-0-0	3
9.	ME-523	Fracture Mechanics	3-0-0	3
10.	ME-524	Heat Treatment and Surface Hardening	3-0-0	3
11.	ME-525	Machine Tool Design	3-0-0	3
12.	ME-526	Material Characterization and Properties	3-0-0	3
13.	ME-527	Materials and Environment	3-0-0	3
14.	ME-528	Materials and Sustainable Development	3-0-0	3
15.	ME-529	Mechanics of Composite Materials	3-0-0	3
16.	ME-530	Methods of Analytical Dynamics	3-0-0	3
17.	ME-531	Modal Analysis of Mechanical Systems	3-0-0	3
18.	ME-532	Modern Control Engineering	3-0-0	3
19.	ME-533	Nonlinear Finite Element Methods	3-0-0	3
20.	ME-534	Nonlinear systems	3-0-0	3
21.	ME-535	Robotics: Mechanics and Control	3-0-0	3
22.	ME-536	Soft Computing Techniques	3-0-0	3
23.	ME-537	Theory of Elasticity	3-0-0	3
24.	ME-538	Theory of Plasticity	3-0-0	3
25.	ME-539	Theory of Plates and Shells	3-0-0	3
26.	ME-540	Tribology	3-0-0	3
27.	ME-541	Vibration Control	3-0-0	3
28.	ME-542	Vibro-Acoustics	3-0-0	3
29.	ME-543	Viscoelasticity	3-0-0	3
30.	ME-544	Wave Propagation in Solids	3-0-0	3
31.	ME-545	Welding and Allied Processes	3-0-0	3

First Semester

MA-553	Computational Methods in Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the stepwise procedure to completely solve a fluid dynamics problem using computational methods
CO2	Ability to solve ODE problems using power series solutions
CO3	Ability to solve PDE using various analytical methods
CO4	Development of a clear understanding on Tensors, their operation and applications.

In relation to mechanical engineering applications, such as, heat transfer, fluid mechanics, vibrations, dynamics and others, the following topics will be covered:

Partial differential equations: Characteristics and classification of 2nd order PDEs. separation of variables special functions, Eigen function expansions, Fourier integrals and transforms, Laplace transforms, methods of characteristics, self-similarity.

Linear algebra: Matrix theory, solution of linear system of algebraic and differential equations; round-off errors, pivoting and ill-conditioned matrices. Eigen values and eigen vectors. Unitary, hermitian and normal matrices.

Numerical Methods: Lagrange interpolation, splines, integration – trapezoid, Romberg, Gauss, adaptive quadrature. Explicity and implicity methods, multi-step methods, Runge-Kutta and predictor-corrector methods, boundary value problems, eigen value problems, systems of differential equations, stiffness. Accuracy, stability and convergence. Alternating direction implicity methods. Non-linear equations.

Books Recommended

1. Ames W F, “Numerical Methods for Partial Differential Equations”, 3rd Edition, Academic Press, New York (1992).
2. Dahlquist G and Björck A, “Numerical Methods”, Prentice-Hall, NJ (1974).
3. Jain M K, Iyengar S R K. and Jain R K, “Numerical Methods for Scientific and Engineering Computations”, 4th Edition New Age International (P) Limited, Publishers, New Delhi (2003).
4. Shampine L F, “Numerical Solution of Ordinary Differential Equations”, Chapman and Hall, New York (1994).
5. Kreyszig, E., "Advanced Engineering Mathematics", 8th Ed, John Wiley, Singapore, 2002.

ME-501	Continuum Mechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to use tensor algebra and calculus for calculations and derivations in general (curvilinear) coordinates
CO2	To understand general stresses and deformations in continuous materials
CO3	Be able to formulate and solve problems in linear and nonlinear elasticity and compressible and incompressible fluid mechanics using the general theory
CO4	Be able to convert the physical description of a problem in continuum mechanics into the appropriate governing equations and boundary conditions and, conversely, provide a physical interpretation for the solutions.

Introduction to Continuum Mechanics

Mathematical Preliminaries: Vector and tensor calculus, Tensor analysis, derivatives of functions with respect to tensors Fields, div, grad, curl, Divergence theorem, transport theorem.

Kinematics: Configurations of a body, displacement, velocity, motion, Deformation gradient, rotation, stretch, strain, strain rate, spin tensor, Assumption of small deformation and small strain.

Balance laws: Balances of mass, linear momentum and angular momentum, Contact forces and the concept of stress, Balance of energy and Clausius-Duhem inequality.

Constitutive relation: Frame indifference, Material symmetry, Kinematic constraints (incompressibility, etc.), Thermodynamical restrictions.

Viscous fluid: constitutive relations, non-Newtonian fluid, boundary value problem**.**

Finite elasticity: Hyperelasticity, isotropy, simple constitutive relations, boundary value problem

Books Recommended

1. Continuum Mechanics, A. J. M. Spencer
2. Continuum Mechanics, P. Chadwick
3. An Introduction to Continuum Mechanics, M. E. Gurtin
4. Introduction to the Mechanics of a Continuous Medium, L. E. Malvern
5. Continuum Mechanics, C. S. Jog

ME-503	**Materials in Mechanical Design**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the importance of materials selection in the Mechanical Design process and use Material property charts, Material Indices for selecting materials for various types of mechanical systems
CO2	Understand the importance of shape and various shape efficiency factors in the design process
CO3	Solve problems involving multiple objectives and constraints
CO4	Designing Hybrid materials and to undertake analysis of Eco properties of materials.

Materials in design, evolution of engineering materials, Design tools and materials data, Function, material, shape and process. Review of properties of Engineering materials and nomenclature of materials.

Material Selection: Introduction, displaying material properties, material property charts Basics concerning material selection, selection strategy, property limits and material indices, selection procedure and structural index. Material selection –case studies

Selection of Materials and Shape: Shape factor, efficiency of standard sections, materials for shape factors, material indices, microscopic or micro-structural shape factor and co-selecting material and shape. Shape case studies.

Multiple constraints and compound objectives selection by successive application of property limits and indices, methods of weight factors, methods using fuzz logic, systematic methods for multiple constraints, compared objectives, exchange constrains and value functions. Case studies.

Process & Process Selection: Processes and their influence attributes, systematic process selection, screening process selection diagrams, Ranking – process cost, supporting information. Case studies related to processing design.

Designing Hybrid Materials: Introduction, Holes in Material Property Space, Types of Hybrids, Composites, Sandwich Structures, Cellular Structures: Foams & Lattices, Segmented Structures, Case Studies

Materials & Environment: Introduction, Material Life Cycle, Materials and energy consuming systems, Eco Attributes of Materials, Eco Selection of Materials, Eco Audits, Case Studies

Books Recommended

1. Ashby M, "Materials Selection in Mechanical Design", Third Edition, Elsevier, Indian Edition, (2005)
2. Ashby M and Johnson K, "Materials & Design, 2nd Edition- The Art & Science of Material Selection in Product Design", Butterworth-Heinemann (2009)
3. Farag M M, "Materials & Process selection for Engineering Design", 2nd Edition, CRC Press (2007)
4. Popov E P, "Engineering Mechanics of Solids", SI Version 2nd Edition, Prentice Hall of India, New Delhi (2003).

ME-505	Finite Element Methods	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Review the mathematical knowledge studied in previous semester
CO2	To understand the advantage of discretization of the object
CO3	To develop familiarities with FEM software
CO4	To develop program for solving the problems.

Fundamentals of the Finite Element Method, discretization of the domain, one-two and three dimensional elements and interpolation functions, local and global coordinates, properties of interpolation functions, compatibility and completeness requirements, Assembly and boundary conditions; Formulation for FEM solutions. Application to solid mechanics, vibrations, plates and shell problems.

Books Recommended

1. Desai and Abel, *"Introduction to Finite Element Method",* East West, CBS Delhi (1987).
2. Zienkiewicz O C, *"Finite Element Method",* McGraw Hill (1989).
3. Krishnamurthy C J, *"Finite Element Method – Analysis Theory and Programming",* Tata McGraw Hill (1994).
4. Bathe k J, *"Finite Element Procedures",* Prentice Hall of India Private Limited, New Delhi, (1996).
5. Belegundu Ashok D and Chandrupatla T, *"Introduction to Finite Element Method",* PHI Private Limited, New Delhi (2003).
6. J. N. Reddy,"An introduction to FEM".

ME-511	Material Selection Laboratory	(0 0 3 2)

Course Outcomes: At the end of the course the student will be able to:

CO1	Use CES Edupack for browsing materials, processes, shapes and sections
CO2	Use CES Edupack for plotting material property charts and use the same for selection problems
CO3	Use CES Edupack for Hybrid materials design
CO4	Use CES Edupack for exploring ECO Design of products.

Material Selection Laboratory course is based upon the use of CES Edupack Software, a material selection package developed by GRANTS Design, Cambridge.

List of Experiment

1. Introduction to CES Edupack- Materials, Families of materials, Materials, Process, Shape Data in CES Edupack.
2. Material Property Charts- Plotting different property charts using CES Edupack
3. Selection of Materials – Selecting Materials using Selection Charts, Material Indices
4. Exploring the Materials, Processes data bases
5. Case Studies on Selecting Materials, Shape
6. Hybrid Materials Design in CES Edupack
7. ECO Data Exploration in CES Edupack.
8. Case Studies using CES Edupack

ME-513	Material Fabrication and Development Laboratory	(0 0 3 2)

Course Outcomes: At the end of the course the student will be able to:

CO1	Fabrication of components using molding processes
CO2	Fabrication of reinforced composites
CO3	Dynamic testing of composites using Dynamic Mechanical Analyzer (DMA)
CO4	Static testing of composites using advanced UTM.

List of Experiment

1. Fabrication of fiber reinforced polymer composite using compression molding
2. Fabrication of carbon nanotube reinforced metal matrix composite using stir casting
3. Fabrication of any component using vacuum bag molding process.
4. Fabrication of any component using resin transfer molding process.
5. Testing of dynamic properties of polymer matrix composites on Dynamic Mechanical Analyzer (DMA)
6. Testing of mechanical properties of metal matrix composites using Advanced UTM.
7. Demonstration of Ultra-sonication process
8. High strain rate testing of polymer based composites using Advanced UTM

Second Semester

ME-502	Advanced Machine Design	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the principles involved in evaluating the shape and dimensions of a component
CO2	Be able to design machine components which are subjected to static/dynamic loads
CO3	To learn to use standard practices and standard data
CO4	To learn to use catalogues and standard machine components.

Introduction to Advanced Machine Design, Materials and processes for machine elements, Review of static strength failure analysis and theories of failure, Fracture and fatigue, High cycle and low cycle fatigue, Design of Machine element against fatigue. Stress-Based Fatigue Analysis, Strain-Based Fatigue Analysis, Fracture Mechanics and Fatigue Crack Propagation, Fatigue Analysis in the

Frequency Domain and Design Problems on fatigue design of shafts and gears, rolling contact bearings (surface fatigue design failure). Stiffness based design. Design to prevent buckling and instability. Introduction to MATLAB Programming for Design.

Books Recommended

1. Norton L R, "Machine Design an Integrated Approach", Ist Indian Reprint, Pearson Education Asia (2001).
2. Sharma P C and Aggrawal D K, "A text book on Machine Design", 9th Edition, S K Kataria and sons (2000).
3. Shigley J E and Mischke C R, "Mechanical Engineering Design" Tata Mcgraw Hill, New Delhi, (2003).
4. Richard W Hertzberg, "Deformation and fracture mechanics of engineering materials", John Wiley and sons, Inc Newyork, (1996).
5. Burr H and John B Cheatham, "Mechanical Analysis and Design", PHI Private Limited, New Delhi (2001).

ME-504	System Dynamics and Control	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the concept of physical systems in multi-energy domains and modeling their dynamics through the unified approach of Bond graph
CO2	Understanding the concept of causality and its implications for deriving system equations from bond graph models
CO3	Understanding and applying principles of classical and modern control theory to the control of multi-energy physical systems
CO4	Ability to simulate models of multi-energy physical systems and analyse their response through case studies.

Introduction to Physical System Dynamics Modeling of Physical System Dynamics: A Unified Approach: Physical systems, Introduction to Bond graphs, Ports, Bonds and Power; Elements of Bond graphs, 1-port elements – resistor R, Stiffness C, and Inertia I, Source of Effort Se and Flow Sf; 2-port elements – Transformer TF and Gyrator GY, with modulation, Junction elements 1 and 0; Causality: Causality for basic 1-port and multi-ports. Derivation of System equations from Bond graphs in first order state space form.

Bond graph modeling of multi-energy systems: Mechanical Systems, Translation and rotation (about a fixed axis), Electrical Systems, Electromechanical Systems, Fluid systems, Transducer models – cylinder, rack and pinion, electromechanical transducers - motors, pumps – positive displacement and centrifugal pump, gear trains, etc.

Analysis of linear systems: Free and forced response for first and second order systems, Undamped and damped oscillator, Derivation of Signal flow graphs from Bond graphs, Derivation of Transfer functions, Bode plots

State variable analysis: State transition matrix, Characteristic equation, Eigen values and Eigen vectors, Their impact on system response, Similarity transformations and their properties, Controllability and Observability, Canonical forms: Controllable, Observable, Diagonal

Stability Criteria: Routh-Hurwitz criterion, Liapunov stability criteria.

Controllers: Pole-placement method, Proportional Integral and Derivative feedback

Simulation and case studies: Computer simulation of Dynamic Systems using Bond graphs

Books Recommended

1. Karnopp, Margolis, Rosenberg, System Dynamics: Modeling and Simulation of Mechatronic Systems, Fourth Edition, Wiley (Higher education), 2005.
2. Karnopp, Margolis & Rosenberg, System Dynamics: A Unified Approach, Wiley , 1990.
3. Amalendu Mukherjee & R. Karmakar, Modeling & Simulation of Engineering Systems through Bond Graphs, Narosa, 2000.
4. Amalendu Mukherjee, Ranjit Karmakar and Arun Kumar Samantaray, Bond Graph in Modeling, Simulation and Fault Identification, I. K. International Publishing House Pvt. Ltd, 2006.
5. EroniniUmez-Eronini, System Dynamics & Control, Brooks/ Cole Publishing Company, 1999. 6. B. C. Kuo, Feedback Control Systems, Prentice Hall.
6. K. Ogata, Modern Control Engineering, Prentice Hall.
7. Bernard Friedland, Control Systems Design, McGraw-Hill.

ME-506	Mechanical Vibrations	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Describe the various fundamentals of vibrations and to represent time domain motion in to frequency domain equation (Fourier series)
CO2	Compute the natural frequencies of vibration of various undamped single degree freedom systems
CO3	Analyze the damped motion without external force for under damped, over damped and critically damped motion
CO4	Analyze harmonic steady state forced vibration systems and related applications
CO5	Explain the different vibration measuring instruments and machine condition monitoring
CO6	Determine the natural frequencies and mode shapes of different two degree and multi degree freedom systems.

Introduction: Brief History of Vibration, importance of study of Vibration, fundamentals of vibration,
classification of vibration. Modeling for vibration - Discrete and continuous vibratory systems.

Single Degree Freedom System: Free vibrations of translational system, torsional system, stability conditions; free vibration with viscous damping, Coulomb damping and Hysteretic damping.

Forced Vibration: Types of excitation, Response of undamped and damped system under – harmonic force, excitation of base, rotating unbalance. Forced response of system with Coulomb and hysteretic damping.

Two Degree Freedom System: Basic concepts, two degree freedom, discrete model for vibratory systems – examples, Equations of motion, Analysis of undamped vibratory systems,, coordinate coupling and principal coordinates, semi-definite system vibration. Forced vibration – frequency response curve and mode shape, stability analysis.

Multidegree Freedom System: Basic concept, modeling, Derivation of equation of motion using – Newton's Second Law, Influence coefficient, Flexibility matrix approach and Lagrange's equation. Eigen value problem and solution.

Natural Frequencies and Mode shapes: Various method for the prediction of natural frequencies and mode shapes – Dunkerley's formula, Raleigh's method, Holzer's method, Matrix Iteration method.

Continuous System: Analysis of transverse vibration of string, longitudinal vibration of bar, Torsional vibration of shaft, and Lateral vibration of beams.

Vibration Control: Need of vibration control – an introduction. Vibration isolation – Force transmitted to the foundation, methods of vibration isolation. Vibration absorbers – basic concept, classification, analysis of undamped and damped vibration absorbers.
Vibration Measurement: Response of vibratory system, vibration measurement scheme, transducers, vibration pickups – seismic instrument, accelerometer. Frequency measurement - Fullarton tachometer, Frahm tachometer and stroboscope.

Books Recommended

1. Rao S S, "Mechanical Vibrations", Pearson Education, Delhi (2004).
2. Roger A A, "Fundamentals of Vibrations", Amerind Publisher Company Private Limited, New Delhi (1999).
3. Srinivas P, "Mechanical Vibration Analysis", Tata McGraw Hill Company Limited, New Delhi (1990).
4. Mallik A K, "Principles of Vibrations Control", Affiliated East West Press Private Limited, New Delhi (2000).
5. Daniel J Inman, "Engineering Vibration", Prentice Hall, New Jersey (2001).

ME-508	**Design and Optimizations**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Student will understand how to formulate an engineering optimization problem and thereafter select appropriate tools needed to solve the problem
CO2	Propagating this uncertainty via various computational methods to predict the output quantity of interest
CO3	Ability to write efficient computer programs related to probabilistic methods
CO4	Be able to analytically obtain the necessary conditions for optimizing a bar of variable cross-section profile for different objective functions and constraints.

Introduction: Introduction to design and specifically system design, Morphology of design with a flow chart. Very brief discussion on market analysis, profit, time value of money, an example of discounted cash flow technique. Concept of workable design, practical example on workable system and optimal design.

System Simulation: Classification. Successive substitution method - examples.Newton Raphson method - one unknown - examples. Newton Raphson method - multiple unknowns - examples. Gauss Seidel method - examples. Rudiments of finite difference method for partial differential equations, with an example.

Regression and Curve Fitting: Need for regression in simulation and optimization. Concept of best fit and exact fit. Exact fit - Lagrange interpolation, Newton's divided difference - examples. Least square regression - theory, examples from linear regression with one and more unknowns - examples. Power law forms - examples. Gauss Newton method for non-linear least squares regression - examples.

Optimization: Introduction, Formulation of optimization problems – examples, Calculus techniques – Lagrange multiplier method – proof, examples, Search methods – Concept of interval of uncertainty, reduction ratio, reduction ratios of simple search techniques like exhaustive search, dichotomous search, Fibonacci search and Golden section search – numerical examples, Method of steepest ascent/ steepest descent, conjugate gradient method – examples. Geometric programming – examples, Dynamic programming – examples, Linear programming – two variable problem –

graphical solution.New generation optimization techniques – Genetic algorithm and simulated annealing - examples.Introduction to Bayesian framework for optimization- examples.

Books Recommended

1. Introduction to optimum design, J.S.Arora, McGraw Hill, 1989.
2. Optimization for engineering design - algorithms and examples, K.Deb, Prentice Hall, 1995.
3. Engineering Optimization: Theory and Practice , S. S. Rao, New age publishers, 2013.

ME-512	**Design of Mechanical System Laboratory**	**(0 0 3 2)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to apply design knowledge for Design of gear box for Lathe machine
CO2	Be able to use FEM software for analysing beam problems
CO3	Be able to model for micromechanical damping for composite materials.

List of Experiment

1. Design of Gear box for Lathe machine
2. Design a Mechanical shaker
3. Nonlinear analysis of beam using FEM
4. Design a overhead traveling crane for dynamic response
5. Modeling for micromechanical damping for composite materials

ME-514	**Advanced Mechanical Vibrations Laboratory**	**(0 0 32)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the working principle of different vibration equipments
CO2	Analysis of damping of beams using model analysis software
CO3	Analysis of damping of Fibre Reinforced Composite lamina and plates
CO4	Analysis of multi degree freedom system.

List of Experiment

1. Study of vibration equipments: Accelerometer, vibration analyzer, Oscilloscope, Hammers
2. Measurement of deflection of cantilever beam using accelerometer
3. Measurement of damping of Al beam
4. Measurement of damping of cast iron using model analysis software
5. Measurement of damping of Fiber reinforced Composite lamina
6. Measurement of damping of Fiber reinforced composite plates
7. Experimental evaluation of multi degree freedom system

Programme Electives

ME-515	Advanced Materials Science	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of mathematics, science & engineering
CO2	To apply and integrate knowledge of material properties to solve material selection problems
CO3	Ability to learn the basics of nanotechnology and apply the concepts for fabrication of advanced materials.

Introduction – Use and Study of Materials, Properties of Materials, Thermal Expansion, Electrical Conductivity, Free Electron Gas and The Ideal Gas, The Drude Model, Large Systems, Statistical Mechanics and The Maxwell–Boltzmann Statistics.

A Brief History of Quantum Mechanics: Its Use in the Drude–Sommerfeld Model, Fermi–Dirac Statistics, Anisotropy, Periodic Potential, Confinement and Quantization, Density of States, Fermi Energy and The Electronic Contribution to Specific Heat at Constant Volume The Reciprocal Space, Wigner–Seitz Cell, Brillouin Zones and The Origin of Bands, Bands, Band Gaps, Free Electron Approximation and Tight Binding Approximation, Material Phenomena Explained using Theories Developed, Superconductivity and The Bose–Einstein Statistics.

Nanomaterials: Physics of Nano-Scale Materials, Classes and fundamentals, properties, synthesis and characterization, Carbon nanotubes: Properties, synthesis and applications, Polymer/CNT, ceramic/CNT, metal/CNT reinforced composite materials.

Graphene: Properties, synthesis and applications, Polymer/graphene, ceramic/ graphene, metal/ graphene reinforced composite materials, Carbon nanofiber and its applications, Carbon foams, Carbon materials for Li-ion rechargeable batteries

Recommended books:

1. Prathap Haridoss. *Physics of Materials: Essential Concepts of Solid-State Physics*
2. Michio Inagaki, Feiyu Kang, Masahiro Toyoda, Hidetaka Konno. *Advanced Materials Science and Engineering of Carbon.*

ME-516	Advanced Solids Mechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Learn about the elastic and plastic behaviour of material and evaluate stress invariants, principal stresses and their directions
CO2	Determine strain invariants, principal strains and their directions
CO3	Develop constitutive relationships between stress and strain for linearly elastic solid
CO4	Analyze theories of failure and design components for safe operation
CO5	Examine the properties of ideally plastic solid and apply the concepts of energy methods in solving structural problems.

Introduction: Basic Concepts in Mechanics, Basic Equations in Mechanics, Classification of the Response of Materials, Solution to Boundary Value Problems.

Mathematical Preliminaries: Overview of Algebra of vectors, Algebra of second order tensors, Algebra of fourth order tensors , Eigen values, eigenvectors of tensors, Transformation laws, Scalar, vector, tensor functions, Gradients and related operators, Integral theorems.

Kinematics : Deformation Gradient, Lagrangian and Eulerian description, Displacement, velocity and acceleration, Transformation of curves, surfaces and volume, Properties of the deformation tensors, Strain Tensors, Normal and shear strain, Homogeneous Motions, Compatibility condition.

Traction and Stress: Traction vectors and stress tensors, Normal and shear stresses, Principal stresses and directions, Stresses on a Octahedral plane, Examples of state of stress, Other stress measuresBalance Laws: Conservation of Mass, Conservation of momentum.

Constitutive Relations: Definition of elastic process , Restrictions on constitutive relation, Isotropic Hooke's law, Material parameters, Restriction on material parameters, Internally constraint materials, Orthotropic Hooke's law.

Boundary Value Problem: Formulation: Formulation of boundary value problem, Techniques to solve boundary value problems Bending of Prismatic Straight Beams: Symmetrical bending, Asymmetrical bending, Shear center.

End Torsion of Prismatic Bars: Twisting of thick walled closed section, Twisting of solid open section, Twisting of hollow section.

Bending of Curved Beams: Winkler-Bach formula for curved beams; 2D Elasticity solution for curved beams.

Beam on Elastic Foundation: General formulation, Example 1: Point load, Example 2: Concentrated moment, Example 3: Uniformly distributed load

Recommended books:

1. Srinath L S. *Advanced Mechanics of Solids*. McGraw Hill Education, New Delhi, 2009.
2. Chadwick P. *Continuum Mechanics: Concise Theory and Problems*. Dover Publications, Inc., New York, 1999.
3. Gurtin M.E. *An Introduction to Continuum Mechanics*, volume 158 of *Mathematics in Science and Engineering*. Academic Press, San Diego, 1970.
4. Kellogg O.D. *Foundations of potential theory*. verlag von julius springer, Berlin, 1929.
5. Sadd M.H. *Elasticity: Theory, Applications and Numerics*. Academic Press, New Delhi, 2005.
6. Ogden R.W. *Non-linear elastic deformations*. Dover publications, New york, 1997.

ME-517	Automotive Design	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the legislation regarding automobiles in India and abroad
CO2	Design Considerations towards Structure, Suspension, Transmission and Vehicle Dynamics of an automobile
CO3	Understanding of propulsion systems
CO4	Application of CAD and CAM
CO5	Case study and awareness regarding participation in national and international competitions.

Socio Economic Aspect of Automotive Mobility Engineering, Safety, Environment and Sustainability Issues. Requirements of Passenger and Commercial Vehicles. Design Considerations for Structure, Suspension, Transmission and Vehicle Dynamics. Study of Different Power Plants Used in Automobiles; Internal Combustion Engines, Battery System and Fuel Cell Technology. Understanding and Application of Computer Aided Engineering Hardware and Software. Application of Renewable Energy in Next Generation Automobiles. Role of Autonomous and Smart Vehicles.

Case Study Regarding Design and Analysis of Automobiles with Respect to Different National and International Competitions.

Recommended books:

1. Crouse, William H., and William Harry Crouse. *Automotive Mechanics*. Tata McGraw-Hill Education, 10th Ed., 2007
2. Bosch, Robert. *Automotive Electrics, Automotive Electronics*. Wiley, 2007.
3. Ehsani, Mehrdad, YiminGao, Stefano Longo, and KambizEbrahimi. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*. CRC press, 2018.

ME-518	Basic Biomechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the role of mechanics in physiology and introduction to biomechanics
CO2	To learn constitutive and decoupling equations to describe segmental movement
CO3	To understand the internal and external flows/deformations, analogous study
CO4	Introduction to different types of muscles and their functioning.

Introduction to Biomechanics. Historical sketch and scope; Mechanics in Physiology; Contributions of Biomechanics to Mechanics.

Segmental movement and vibrations; Generalized Coordinates, Lagrange's Equations, Normal Modes of Vibration, Decoupling of Equations of Motion, Muscle Forces, Segmental Movement and Vibrations, Systems with Damping and Fluid Dynamic Loads, Sufficient Conditions for Decoupling Equations of System with Damping.

Constitutive equations: Application to solids and fluids in biomechanics; Stress, Strain, Strain Rate, Constitutive Equations, The Non viscous Fluid, The Newtonian Viscous Fluid, The Hookean Elastic Solid, The Effect of Temperature, Materials with More Complex Mechanical Behavior, Viscoelasticity, Response of a Viscoelastic Body to Harmonic Excitation, Use of Viscoelastic Models, Methods of Testing, Mathematical Development of Constitutive Equations.

Description of internal deformation and forces; Use of Curvilinear Coordinates, Description of internal Forces, Work and Strain Energy, Calculation of Stresses from the Strain Energy Function, Complementary Energy Function, Rotation and Strain.

External Flow: Fluid dynamic forces acting on moving bodies; Flow Around an Airfoil, Flow Around Bluff Bodies, Steady-State Aeroelastic Problems, Transient Fluid Dynamic Forces Due to Unsteady Motion, Flutter, Kutta-Joukowski Theorem, The Creation of Circulation Around a Wing, Circulation and Vorticity in the Wake, Vortex System Associated with a Finite Wing in Nonstationary Motion, Thin Wing in Steady Flow, Lift Distribution on a Finite Wing, Drag.

Flying and swimming; Comparing Birds and Insects with Aircraft, Forward Flight of Birds and Insects, Hovering and Other Modes of Motion, Aquatic Animal Propulsion, Stokeslet and Dipole in a Viscous Fluid, Motion of Sphere, Cylinder, and Flagella in Viscous Fluid, Resistive-Force Theory of Flagellar Propulsion, Theories of Fish Swimming, Energy Cost of Locomotion, Cell Movement.

Skeletal muscle; The Functional Arrangement of Muscles, The Structure of Skeletal Muscle, The Sliding Element Theory of Muscle Action, Single Twitch and Wave Summation, Contraction of Skeletal Muscle Bundles, Hill's Equation for Tetanized Muscle, Hill's Three- Element Model, Hypotheses of Cross-Bridge Theory, Evidences in Support of the Cross-Bridge Hypotheses, Mathematical Development of the Cross-Bridge Theory, Constitutive Equation of the Muscle as a Three-Dimensional Continuum,

Heart Muscle; The Difference Between Myocardial and Skeletal Muscle Cells, Use of the Papillary or Trabecular Muscles as Testing Specimens, Use of the Whole Ventricle to Determine Material Properties of the Heart Muscle, Properties of Unstimulated Heart Muscle, Force, Length, Velocity of Shortening, and Calcium Concentration Relationship for the Cardiac Muscle, The Behavior of Active Myocardium According to Hill's Equation and its Modification, Pinto's Method, Micromechanical Derivation of the Constitutive Law for the Passive Myocardium.

Smooth Muscles; Types of Smooth Muscles, The Contractile Machinery, Rhythmic Contraction of Smooth Muscle, The Property of a Resting Smooth Muscle: Ureter, Active Contraction of Ureteral Segments, Resting Smooth Muscle: Taenia Coli, Other Smooth Muscle Organs.

Bone and Cartilage; Bone as a Living Organ, Blood Circulation in Bone, Elasticity and Strength of Bone, Viscoelastic Properties of Bone, Functional Adaptation of Bone, Cartilage, Viscoelastic Properties of Articular Cartilage, The Lubrication Quality of Articular Cartilage Surfaces, Constitutive Equations of Cartilage According to a Triphasic Theory, Tendons and Ligaments.

Books Recommended

1. Y. C. Fung, Biomechanics: Motion, Flow, Stress, and Growth, Springer, 1990.
2. Y. C. Fung, Biomechanics: Mechanical Properties of Living Tissues, 2nd Edition, Springer, 1993.
3. A. Freivalds, Biomechanics of the upper limbs: Mechanics, Modeling, and Musculoskeletal Injuries, CRC Press, 2004.
4. Fundamentals of Biomechanics, Duane Knudson, , 2nd Edition, Springer, 2007.

ME-519	**Computer Aided Design**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the basic fundamentals of computer aided design and manufacturing
CO2	To learn 2D & 3D transformations of the basic entities like line, circle, ellipse etc
CO3	To understand the different geometric modelling techniques like solid modelling, surface modelling, feature based modelling etc. and to visualize how the components look like before its manufacturing or fabrication
CO4	To learn the part programming, importance of group technology, computer aided process planning, computer aided quality control
CO5	To learn the overall configuration and elements of computer integrated manufacturing systems.

Introduction: Definitions, Historical Development. Nameable and Unnamable shapes, Explicit and Implicit Equations, Intrinsic Equations, Parametric Equations, Coordinate Systems.

Curves: Algebraic and Geometric Forms, Parametric space of a curve, Blending functions, Reparametrization, Truncating, Extending and subdividing, Space curve, Four point form, Straight lines, Spline Curves, Bezier Curves, B-spline Curves, Rational Polynomials, introduction to NURBS.

Geometric Transformation and Projection: Transformations: Translation, Rotation, Scaling Symmetry and Reflection, Homogeneous Transformations. Orthographic Projections, Axonometric Projections, Oblique Projections, Perspective Transformation.

Surfaces: Algebraic and Geometric form, Tangent and Twist Vectors, Normal, Parametric space of a surface, Blending Functions, Reparametrization of a surface patch, subdividing, Sixteen Point form, Four Curve Form, Plane surface, Cylindrical Surface, Ruled surface, Surface of Revolution. Bezier Surface, B-Spline Surface.

Solid Modelling Fundamentals: Topology of Closed Paths, Piecewise flat surfaces, topology of closed curved surfaces, Generalized Concept of boundary, Set theory, Boolean operators, Set-membership Classification, Euler operators, Formal Modelling Criteria.

Solid Model Construction: Graph Based methods, Boolean models, Instances and Parameterized Shapes, Cell Decomposition and spatial-Occupancy Enumeration, Sweep Representation, Constructive Solid Geometry, Boundary Representation. Assemble Modelling.

Data transfer formats: Neutral data format, IGES, STEP and XML.

Applications of Solid Models: Rapid Prototyping, FEM, Medical Applications**.**

Books Recommended

1. Geometric Modelling: Michael E. Mortenson, John Wiley, 2006
2. Mathematical Elements of Computer Graphics: Roger and Adams, McGraw Hill, 1994.
3. CAD CAM Theory and Practice: I. Zeid, McGraw Hill, 1994.

ME-520	**Continuum Damage Mechanics**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to explain the macroscopic through the concept of Continuum Damage Mechanics.
CO2	To properly estimate the value of damage when designing reliable structures it is necessary to formulate the damage phenomenon in terms of mechanics
CO3	To analyse various engineering problems using analytical and computational techniques.

Essentials of Continuum mechanics: Tensorial notation, stress, strain, invariants, equilibrium equations, Domain and validity of continuum damage mechanics, concept of representative volume element.

Phenomenological aspects of damage: Damage, measurement of damage, modeling of damage through effective area reduction, void volume fraction and stiffness reduction, representation of damage through different orders of tensors, concept of effective stress, hypothesis of strain equivalence, strain energy equivalence, and complementary strain energy equivalence.

Thermodynamics of damage: State variables, damage as state variables, first and second law of thermodynamics, thermodynamics potentials, dissipation potentials, constitutive equations, evolution equations.

Kinetic Laws of Damage Evolution: Unified formulation of damage laws, damage laws for brittle, quasi-brittle, ductile, creep, low cycle and high cycle fatigue.

Damage Analysis of Structures: Implementation of isotropic damage theory, case studies from literature.

Books Recommended

1. A Course on damage mechanics: Jean Lemaitre.
2. Continuum damage mechanics: S. Murakami.
3. Mechanics of solid materials: Jean Lemaitre and J. L. Chaboche.
4. An Introduction to damage mechanics: L. M. Kachanov.

5. Damage mechanics: Dusan Krajcinovic.
6. Damage mechanics: George Z. Voyiadjis and Peter I. Kattan.

ME-521	**Control Theory and Applications**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Learn the basics of control systems and understand how to build the transfer functions of simple mechanical systems.
CO2	Understand the design of various controllers such as PID controller and predict the response of simple systems
CO3	Understand about gain and phase margin. Learn the concept of active vibration control
CO4	Design various mechanical systems and predicts its behaviour by plotting root locus diagram
CO5	Learn and apply the state space model to simple systems. Design and solve few problems by using digital control system.

Introduction to automatic controls. Modeling of flow, heat transfer and electrical, pneumatic and vibration systems. Block diagram and transfer function. Modeling of continuous systems. Extraction of reduced order models. Transient and frequency response evaluation using Laplace transform. Characteristics of hydraulic controller, pneumatic, electronic controller, electro-hydraulic and electro-pneumatic controllers.PID control. Stability Gain and phase margins. Control system design using root and compensation. Application to Machine tool, Boiler, Engine Governing, Aerospace, Active vibration control, etc. Auto-tuning. Sequence control, Logic diagram. Introduction to digital control, Implementation using computer. Introduction to control of MIMO systems. State Space modeling. Tutorials for control problems in these areas using MATLAB.

Books Recommended:

1. Gopal M, "*Modern Control System Theory*", John Wiley & Sons (16 May 1984)
2. Gopal M and Nagrath I.J, "*Control Systems Engineering*", New age international publishers (2007)
3. Ogata K, "*Modern Control Engineering (5th Edition)*", Prentice Hall International UK London (1997)

ME-522	**Design of Fluid Film Bearings**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding of basic governing equations related to lubrication mechanisms
CO2	Understanding of different boundary conditions for fluid film bearings and their use
CO3	Understanding of analytical and numerical solutions of governing equations for fluid film bearings
CO4	Knowledge of different types of bearings such as porous, gas, hybrid bearings.

Mechanics of lubricant films and basic equations: Lubricant, Lubricant properties, Lubrication regimes, Viscosity index, Pertoff's Equation, Equation of continuity, momentum and energy, Generalized Reynolds Equation, Simplification of Full Reynolds Equation, Three different boundary conditions i.e. Full Sommerfeld Condition, Half Sommerfeld and Reynolds.

Thrust Bearings: Geometry, Infinite thrust bearing, Pressure distribution, Center of pressure, Load carrying capacity, Friction, Finite thrust bearing.

Journal Bearings: Geometry, Short and infinite long bearing, Pressure distribution, Load carrying capacity, Attitude angle, Friction, Adiabatic solution for journal bearing, Finite journal bearing.

Others types of Bearings: Analytical and numerical solutions of Hydrodynamic porous bearings, Hydrodynamic gas bearings, Hybrid bearing.

Case studies: Related to fluid film bearing problems

Books Recommended

1. Hamrock, Schmid, Jacobson. *Fundamentals of Fluid Film Lubrication*.
2. Khonsari and Booser. *Applied Tribology Bearing Design and Lubrication*
3. Cameron. *Principles of Lubrication*
4. Bhushan, B. *Principles and Applications of Tribology*
5. Fukao, Oshima, Takemoto, Dorell. *Magnetic Bearings and Bearingless Drives*.
6. Ghosh, Majumdar, Sarangi. *Theory of Lubrication.*

ME-523	**Fracture Mechanics**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To learn about the stress intensity factor approach, LEFM approach, CMOD approach and J integral fracture criteria
CO2	Having knowledge of various parameters related with fracture mechanics evaluation
CO3	Determining the safe designs for structures and components.

Linear elastic fracture mechanics- Energy approach and stress intensity factor approach. General yielding fracture mechanics. Concept of crack opening displacement and J integral fracture criteria. Evaluation of fracture mechanics parameters. Fracture safe designing of structures and machine components. Service failure analysis.

Books Recommended

1. Richard W. Hertzberg Deformation and Fracture Mechanics of Engineering Materials
John Wiley & Sons Inc 1995
2. S. D. Antolovich, "Fundamentals of Fracture Mechanics" Academic Pr 2009
3. A Saxena "Non-Linear Fracture Mechanics for Engineers" CRC Press 2009

ME-524	**Heat Treatment and Surface Hardening**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of science & engineering
CO2	To apply and integrate the knowledge of phase transformation to analyze the material behaviour
CO3	Ability to learn the basics of heat treatment and apply the concepts for processing of advanced materials.

Introduction: Definition (Materials tetrahedron perspective) –Aim & Theory of Heat Treatment (Why, How, What) -Structure of Metals and Alloys and Materials - Phase diagram and phase transformation, Relation between thermodynamics and Kinetics for phase transformation.

Phase transformation and heat treatment (Time and temperature influence): Concept of JKMA equation and TTT diagram -Heat treatment time and temperature and microstructure/property developed, CCT diagram from TTT diagram and experimental data and its implication to heat treatment, Some heat treatments, like annealing, normalizing, hardening, tempering of steel on the basis of TTT and CCT diagram and properly-microstructure correlation, Introduction to Precipitation hardening.

Introduction to Heat Treatment of Alloys(Al-alloy and Steel): Theory of Heat Treatment (Why, How, What), Thermodynamic basis for heat treatment of alloys, Phase diagram and phase transformation in alloys, Choice of composition and temperature for heat treatment and related phase transformation in Al-alloys, Choice of composition and temperature for heat treatment and related phase transformation in steel, Theory of Heat Treatment-Hardenability and Jominy test, Case hardening of Alloy systems for Steels

Books Recommended

1. Principles of Heat Treatment of Steels by R.C. Sharma
2. Phase Transformations in Metals and Alloys by D.A. Porter and K.E. Easterling (Taylor and Francis)
3. Engineering Physical Metallurgy and Heat Treatment by Y. Lakhtein (Mir Publisher)

ME-525	Machine Tool Design	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To learn the importance of machine tool design in metal cutting and systematic approach to design machine tools
CO2	To design the structural components in order to achieve desired elastic and fatigue properties
CO3	Use of design software to design the machine tools
CO4	To learn the working principle and recent developments in the area of CIMS and CNC manufacturing systems.

Design requirements of machine tools, Design approach for machine tools, identification and quantification of objectives and constraints in machine tool design. Estimation of power requirements and selection of motor for metal cutting machine tool spindles. Design of gearbox, spindle and guide-ways. Principles of design of structural components, namely, head stock, tail stock, carriage, table, knee, column and over arms to achieve desired static and fatigue strength, stiffness, dynamic characteristics and other requirements. Exercises on the design of machine tools using existing CAD software packages.

Introduction to computer integrated manufacturing systems and CNC machine tools. Design/selection of linear motion systems, ball, screws, CNC feedback devices, controllers, feed drives and servomotors for CNC machine tools.Recent developments in CNC and other machine tools.

Books Recommended

1. Devris W R, "Analysis of Material Removal Processes", Springer – Verlag, 1992.
2. N Acherkan , "Machine Tool Design" , Volume- 1-4, MIR Publishers, Moscow, 1969
3. Mishra P K, "Non Conventional Machining", Narosa Publishing House, New Delhi, 1977Edition.
4. Panday P C, Shan H S, "Modern Machining Processes", Tata McGraw Hill PublishingCompany Limited, New Delhi, 1980 Edition.
5. Schey A, John, "Introduction to Manufacturing Processes", McGraw Hill Book Company,New York, 1987.
6. Jain R K, "Production Technology", Khanna Publishers Delhi, 1995.
7. HMT Bangalore, "Production Technology", Tata McGraw Hill, New Delhi, 1980.

ME-526	Material Characterization and Properties	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of mathematics, science & engineering
CO2	To apply and integrate knowledge of various material characterization techniques for development of advanced materials
CO3	Ability to learn the basics of material properties and apply the concepts for characterization of advanced materials.

Light microscopy, X-ray diffraction methods, Transmission electron microscopy, Scanning electron microscopy, scanning tunneling microscopy, scanning probe microscopy, X-ray spectroscopy for elemental analysis, Electron spectroscopy for surface analysis, SIMS for surface analysis, Vibrational spectroscopy for molecular analysis, DTA and DSC analysis, Thermogravimetry.

Books Recommended

1. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods – Yang Leng, John Wiley & Sons.
2. Materials Characterization Techniques-Sam Zhang, Lin Li, Ashok Kumar, CRC press.

ME-527	Materials and Environment	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the importance of materials and interrelationship between Materials, Energy, Emissions and Environment
CO2	Carryout Life Cycle Assessment (LCA), Eco Audits using various methods
CO3	Understand the importance of materials selection in the Mechanical Design process and use Material property charts, Material Indices for selecting materials for various types of mechanical systems
CO4	Introduce the concept of Ecological Selection of Materials.

Introduction Material Dependence: Introduction and synopsis, Materials: a brief history, Learned dependency: the reliance on nonrenewable materials, Materials and the environment.

Resource Consumption & its drivers: Resource consumption, Exponential growth and doubling times, Reserves, the resource base, and resource life, Summary and conclusion.

The Materials Life Cycle: The material life cycle, Life-cycle assessment: details and difficulties, Streamlined LCA, The strategy for eco-selection of materials.

End of First Life- A Problem or a resource: What determines product life, End-of-first-life Options, The problem of packaging, Recycling: resurrecting materials.

Eco Data-Values, Sources, precision: Data precision- recalibrating expectations, The eco-attributes of materials, Energy and CO2 footprints of energy, transport, and use, Exploring the data: property charts.

Eco Audits & Eco Audit Tools: Introduction and synopsis, Eco-audits, Computer-aided eco-auditing, Case Studies.

Selection Strategies: Introduction, The selection strategy: choosing a car, Principles of materials selection, Selection criteria and property charts, Resolving conflicting objectives: tradeoff methods.

Eco-Informed Material Selection: Which bottle is best? Selection per unit of function, Crash barriers: matching choice to purpose, Deriving and using indices: materials for light, strong shells, Heating and cooling, Transport.

Sustainability- Living on Renewables: The ecological metaphor, Sustainable energy, sustainable materials, Future options.

Books Recommended

1. Ashby M, " Materials & the Environment- Eco-Informed Material Choice" , Butterworth-Heinemann (2019)
2. Ashby M, " Materials and Sustainable Development", Butterworth-Heinemann (2016)
3. Ashby M, "Materials Selection in Mechanical Design", Third Edition, Elsevier, Indian Edition, (2005)
4. Ashby M and Johnson K, "Materials & Design, 2nd Edition- The Art & Science of Material Selection in Product Design", Butterworth-Heinemann (2009)

ME-528	**Materials and Sustainable Development**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the importance of materials and interrelationship between Materials, Energy, Emissions and Environment
CO2	Carryout Life Cycle Assessment (LCA), Eco Audits using various methods
CO3	Understand the meaning and importance of sustainable development, assessment methods/techniques for sustainable development with various case studies
CO4	Evaluate Materials supply chain risk and understand concept of CSR.

Introduction Material Dependence: Introduction and synopsis, Materials: a brief history, Learned dependency: the reliance on nonrenewable materials, Materials and the environment.

Resource Consumption & its drivers: Resource consumption, Exponential growth and doubling times, Reserves, the resource base, and resource life, Summary and conclusion.

The Materials Life Cycle: The material life cycle, Life-cycle assessment: details and difficulties, Streamlined LCA, The strategy for eco-selection of materials.

Eco Data-Values, Sources, precision: Data precision- recalibrating expectations, The eco-attributes of materials, Energy and CO2 footprints of energy, transport, and use, Exploring the data: property charts.

Eco Audits & Eco Audit Tools: Introduction and synopsis, Eco-audits, Computer-aided eco-auditing, Case Studies.

Sustainable Development: Introduction, Definitions, Triple Bottom Line Approach, Articulations of sustainable development, Assessing sustainable development, layered approach to assess sustainable development, Tools for assessment, Defining objective, stake holder analysis, fact finding, synthesis.

Materials Supply chain risk: Emerging constraints on materials sourcing and usage, price volatility risk, monopoly of supply and geo political risk, conflict risk, legislation & regulation risk, other risks.

Corporate Sustainability & materials: Introduction, Corporate social responsibility & sustainability reporting, Case Studies on Corporate SR's.

Case Studies on Sustainable development: Biopolymers to replace oil based plastics, Wind Farms, Electric Cars, Solar PV for Low Carbon power, Bamboo as sustainable building material.

Books Recommended

1. Ashby M, " Materials and Sustainable Development", Butterworth-Heinemann (2016)
2. Ashby M, " Materials & the Environment- Eco-Informed Material Choice" , Butterworth Heinemann (2019)
3. Ashby M, "Materials Selection in Mechanical Design", Third Edition, Elsevier, Indian Edition, (2005)
4. Ashby M and Johnson K, "Materials & Design, 2nd Edition- The Art & Science of Material Selection in Product Design", Butterworth-Heinemann (2009)

ME-529	**Mechanics of Composite Materials**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of mathematics, science & engineering
CO2	To apply and integrate knowledge of different processes of composite fabrication for making advanced composite materials
CO3	Ability to learn the basics of composite mechanics and apply the concepts for making lightweight composites with high strength.

Introduction: Definition of composite, load transfer mechanism, classification of composites, advantages and applications of composites, fibers, matrix materials and their properties.

Basic concepts of solid mechanics: General state of stress, equilibrium equations, tensors – constitutive equations, plane stress, plane strain and strain energy concept.
Micromechanics of Composites: 3-D constitutive equations: Generalized Hooke's Law - orthotropic, transversely isotropic and isotropic materials. Engineering constants, stiffness and compliance matrix, stress and strain transformation, transformed stiffness and compliance matrix. Lamina stress-strain relations in principal and global coordinates. Thermal Stress.

Micromechanics of Composites: Basic concepts, fiber packing geometry, micromechanical methods for prediction of properties of fiber-reinforced composites – Longitudinal, transverse and shear moduli, Poisson's ratios, tensile and compressive strength.

Composite Laminates: Basic concepts of classical lamination theory (CLT) – laminate stress. Laminate stiffness – A-B-D matrix, and their implications.

Failure Theories: Application of theories of failure to fiber – reinforced composites, failure mechanisms, maximum stress, maximum strain, Tsai-Hill theory, Tsai-Wu theory of failure. Comparison of failure criteria.
Dynamic behavior: Linear viscoelastic behavior, creep and relaxation, differential equations ands pring dashpot models. Complex modulus, elastic-viscoelasitc correspondence principle, longitudinal, flexural vibrations of composite beams and transverse vibrations of laminations, analysis of damping in composites.

Books Recommended

1. Broutman L J and Krock R H "Modern Composite Materials", Addison Wesley Publishing Company, 1967.
2. Jones R M "Mechanics of Composite Materials", Scripta Book Company, 1975.
3. Herkovic C T "Mechanics of Fibres Composites", University of Virginia, John Wiley and Sons, Inc, 1998.

4. Tsai Stephen W “Introduction to Composite Materials”, Technomic Publishing Company Inc., 1980.
5. 5. Gibson R F, “Principles of Composites Materials Mechanics”, McGraw Hill International Edition, New York, 1994.
6. Hyer M W, “Stress analysis of Fiber-Reinforced Composites Materials”, WCB McGraw Hill, Boston, 1997.
7. Halpin J C, “Primer on Composite Materials Analysis”, Technomic Publishing Company Inc, Lanchester, 1992

ME-530	Methods of Analytical Dynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the basic fundamentals of mechanics and governing laws to describe the force and motion systems
CO2	To learn different laws and principles in analytical mechanics and different motions of coordinates and reference frames
CO3	Behaviour and stability of dynamical and non-autonoums systems.

Fundamentals of Newtonian Mechanics: Historical survey of Mechanics, Newton’s Laws, Impulse and Momentum, Moment of a Force and Angular Momentum, Work and Energy, Energy Diagrams, Systems of Particles, The Two-Body Central Force Problem, The Inverse Square Law, Orbits of Planets and Satellites, Scattering by a Repulsive Central Force.

Fundamentals of Analytical Mechanics: Degree of Freedom. Generalized Coordinates, System with Constraints, The Stationary Value of a Function, The Stationary Value of a Definite Integral, The Principle of Virtual Work, D’Alembert’s Principle, Hamilton’s Principle, Lagrange’s Equations of Motion, Lagrange’s Equations for Impulsive Forces, Conservation Laws, Routh’s Method for the Ignoration of Coordinates, Rayleigh’s Dissipation Function, Hamiltion’s Equations.

Motion Relative to Rotating Reference Frames: Transformation of Coordinates, Rotating Coordinates Systems, Expressions for the Motion in Terms of Moving Reference Frames, Motion Relative to the Rotating earth, Motion of a Free Particle Relative to the Earth, Foucault’s Pendulum.

Rigid Body Dynamics: Kinematics of a Rigid Body, The Linear and Angular Momentum of a Rigid Body, Translation Theorem for the angular Momentum, The Kinetic Energy of a Rigid Body, Principle Axes, Moment-Free Inertially Symmetric Body, General Case of a Moment-Free Body, Motion of a Symmetric Top, The Lagrangian Equation of Quasi-Coordinates, The Equations of Motion Referred to an Arbitrary System of Axes, The Rolling of a Coin.

Behaviour of Dynamical Systems. Geometrical Theory: Fundamental Concepts, Motion of Single-Degrees-of Freedom Autonomous Systems about Equilibrium Points, Conservative Systems. Motion in the Large, The Index of Poincaré, Limit Cycles of Poincaré.

Stability of Multi-Degree-of-Freedom Autonomous Systems: General Linear Systems, Linear Autonomous Systems, Stability of Linear Autonomous Systems. Rourh-Hurwitz Criterion, The Variational Equations, Theorem on the First-Approximation Stability, Variation from Canonical Systems. Constant Coefficients, The Liapunov Direct Method, Geometrical Interpretation of the Liapunov Direct Method, Stability of Canonical Systems, Stability in the Presence of Gyroscopic and Dissipative Forces, Construction of Liapunov Function for Linear Autonomous Systems.

Non-autonomous Systems: Linear Systems with Periodic Coefficients. Floquet’s Theory, Stability of Variational Equations with Periodic Coefficients, Orbital Stability, Variuation from Canonical Systems, Periodic Coefficients, Second-Order Systems with Periodic Coefficients, Hill’s Infinite determinant, Mathieu’s Equation, The Liapunov Direct Method.

Analytical Solution by Perturbation Techniques: The Fundamental Perturbation Technique, Secular Terms, Lindstedt's Methods, The Krylov-Bogoliubov-Mutroposlsky (KBM) Method, A Perturbation Technique Based on Hill's Determinations, Periodic Solutions of Non-autonomous Systems. Duffing's Equation, The Method of Averaging.

Transformation Theory. The Hamilton-Jacobi Equations: The Principle of Least Action, Constant Transformations, Further Extensions of the Concept of Contact Transformations, Integral Invariants, The Langrange and Poisson Brackets, Infinitesimal Contact Transformations, The Hamilton-Jacobi Equation, Separable Systems, Action and Angule Variables, Peturbation Theory.

Books Recommended

1. Leonard Meirovitch, "Methods of Analytical Dynamics", First South Asian Edition, Dover Publications Inc., 2007.
2. H. Goldstein, Classical Mechanics, Pearson, 2011.
3. Francis B. Hildebrand, *Methods of Applied Mathematics*, 2nd Edition, Dover PublicationsInc., 2002.

ME-531	Modal Analysis of Mechanical System	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Learn the basics of mechanical vibrations and predict the modal-model i.e., natural frequencies, mode shapes and damping coefficient of simple systems. Understand the concept of state- space model. Also, learn the concept of frequency response function (FRF)
CO2	Understand the vibration measuring instruments and predict the FRF at different excitations
CO3	Design the FRF for Single and multi-degree of freedom systems
CO4	Understand the modal-model, response model, spatial models, mobility skeletons and system models. Learn the application of experimental modal analysis on mechanical systems.

Overview: Applications of Modal Testing, Philosophy of Modal Testing, Summary of Theory, Summary of Measurement Methods, Summary of Modal Analysis Processes, Review of test procedures, and levels, Terminology and Notation.

Theoretical Basis: Single-Degree-of Freedom (SDOF) system theory, Presentation and properties of FRF Data for SDOF system, Undamped Multi-Degree-of Freedom (MDOF) system, MDOF systems with proportional damping, MDOF systems with structural (hysteretic) damping – General case, MDOF systems with viscous damping – general case, Modal Analysis of Rotating Structures, Complex Modes, Characteristics and presentation of MDOF FRF Data. Non-sinusoidal Vibration and FRF properties.

Response Function Measurement Techniques: Basic measurement system, Structure Preparation, Excitation of the Structure, Transducers and amplifiers, Analyzers, Digital signal processing, use of different excitation signals, calibration, mass cancellation, rotational FRF measurement, measurements on non-linear structures, multi-point excitation methods, measuring FRFs and ODSs using the scanning LDV.

Modal Parameter Extraction Methods: Preliminary checks of FRF data, SDOF modal analysis, methods, MDOF modal analysis in the frequency domain (SISO), global modal analysis in the time domain, modal analysis of non-linear structures, concluding comments.

Derivation of Mathematical Models: Modal models, refinement of modal models, display of modal model, response model, spatial models, mobility skeletons and system models.
Applications: Comparison of and correlation of experiment and prediction, adjustment or updating of models, coupled and modified structure analysis, response prediction and force determination, test planning.

Books Recommended

1. Ewins D J, "Modal Testing: Theory and Practice" Research Studies Press Ltd 1985.
2. He and fu "Modal Analysis" Elsevier Science & Technology 2001.
3. J M M Silva & N M M Maia "Modal Analysis and Testing" Kluwer Academic Publishers Group 1999.
4. G Conciauro, M Guglielmi, R Sorrentino "Advanced Modal Analysis" John Wiley & Sons 2000.

ME-532	Modern Control Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the physical significance of control systems
CO2	Dynamic response, mathematical modelling and analogy between different systems
CO3	To design and analyse different control systems
CO4	Characteristics and performance of feedback control systems and Introduction to digital control systems.

Introduction to Control Systems. Historical perspective leading to modern control engineering;

Mathematical Modeling of Dynamic Systems: Mechanical, Electrical, Fluid, Thermal Systems, etc. State variable models;

Dynamic response: Transient and Steady-State Response Analyses

Characteristics and performance of feedback control systems:

Stability in the frequency and time domains: Lyapunov stability;

Control systems analysis and design: Root-locus method, frequency-response method;

Control systems analysis and design in state space: Controllability and Observability, Pole placement using feedback, the separation principle and estimator design, PID Controllers

Digital control systems: Sampled-data systems, stability analysis, compensation, implementation of digital controllers;

Case studies: Computer simulation of dynamic systems.

Books Recommended

1. G. F. Franklin, J. D. Powell, A. Emami-Naeini, Feedback Control of Dynamic Systems, Pearson Education Inc., 2002.
2. R. C. Dorf, R. H. Bishop, Modern Control Systems, Addison-Wesley Longman Inc. 1998.
3. B. C. Kuo, Feedback Control Systems, Prentice Hall.
4. K. Ogata, Modern Control Engineering, Prentice Hall.
5. EroniniUmez-Eronini, System Dynamics & Control, Brooks/ Cole Publishing Company,1999.
6. N. S. Nise, Control Systems Engineering, John Wiley & Sons (Asia) Pte. Ltd., Singapore,2004.
7. Bernard Friedland, Control Systems Design, McGraw-Hill.

8. Graham C Goodwin, Stefan F Graebe, Mario E Salgado, Control System Design, Pearson Education Inc., 2001.
9. Karnopp, Margolis, Rosenberg, System Dynamics: Modeling and Simulation of Mechatronic Systems, Fourth Edition, Wiley (Higher education), 2005.
10. Amalendu Mukherjee, Ranjit Karmakar and Arun Kumar Samantaray, Bond Graph in Modeling, Simulation and Fault Identification, I. K. International Publishing House Pvt. Ltd, 2006.
11. NPTEL lectures on modern control engineering

ME-533	**Nonlinear Finite Element Method**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	understanding of the practical use of computer programs for numerical simulation of nonlinear finite element analysis
CO2	to learn about applications of finite element procedures to nonlinear Structural / Solid Mechanics problems
CO3	The formulation of finite element procedure to solve boundary value problems involving above nonlinearities
CO4	To expose the student to implementing algorithms in finite element codes and debugging them through example problems
CO5	The student will acquire the skill to implement the algorithms via user-defined subroutines in general purpose finite element codes like ANSYS and ABAQUS.

Introductory lecture: review of Linear Finite Element Methods, presentation of course content.

Demonstration lecture on Abaqus: Installation and running the software, geometric modelling, writing user subroutine – UMAT.

Review of continuum Mechanics: Tensor algebra & Calculus, Kinematics, Stress measures, Clausius Duhem inequality, Objectivity with examples, objective rates used in non-linear finite element computations – comparisons using examples.

Variational calculus – formulating linear and non-linear mechanics problems, Introduction to Directional derivative.Directional derivative – variation of various stress and strain measures, Introduction to Linearization.

Introduction to Total and Updated Lagrangian formulations – derivation of weak forms, Solution methods – Newton Raphson method and variants.

Updated Lagrangian formulation: Discretized FE equations using IsoParametric formulation Restrictions on the constitutive equations imposed by frame indifference and thermodynamics.

Constitutive equations for hyperelasticity (with and without incompressibility), rate dependent and independent plasticity in metals and Crystal plasticity.

Linearization of constitutive equations to be used in weak forms, and FE discretisation: Example – Compressible, Neo-Hookean material (other constitutive formulations may also be taken up here).

Geometric and material stiffness matrices – details of implementation, writing User subroutine UEL in Abaqus.

Convergence measures: rate of convergence, Patch test
Geometric and material stiffness matrices: discussion on rank, deficiency and implementation details.

Discussion of techniques: incompressibility condition. Gauss Quadrature, Reduced integration, Locking issues.

Books Recommended

1. Ted Belytschko, Nonlinear Finite Elements for Continua and Structures. John Wiley & Sons, Ltd..K. J. Bathe, Finite Element Procedures. Prentice – Hall Ltd.
2. M. A. Crisfield, Non-linear Finite Element Analysis: Essentials (Volume 1), John Wiley & Sons, Ltd.
3. M. A. Crisfield, Non-linear Finite Element Analysis: Advanced topics (Volume 2), John Wiley & Sons, Ltd.

ME-534	**Nonlinear Systems**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	The ability to understand the characteristics of various types of nonlinearities present in physical systems
CO2	The ability to carry out the stability analysis of non-linear control systems
CO3	The ability to carry out the analysis and design of control systems
CO4	The ability to analyze the effect sampling on stability, controllability and observability
CO5	The ability to design digital controllers for industrial applications.

Introduction: Nonlinear Models and Nonlinear Phenomena, Examples Pendulum Equation, Tunnel-Diode Circuit, Mass-Spring System, Negative-Resistance Oscillator, Artificial Neutral Network, Adaptive Control, Common Nonlinearities.

Second-Order Systems: Qualitative Behaviour of linear Systems, Multiple Equilibria, Qualitative Behaviour Near Equilibrium Points, Limits Cycles, Numerical Construction of Phase Portraits, Existence of Periodic Orbits, Bifurcation.

Fundamental Properties: Existence and Uniqueness, Continuous Dependence on Initial Conditions and Parameters, Differentiability of Solutions and Sensitivity Equations, Comparison Principle.

Lyapunov Stability: Autonomous Systems, The Invariance Principle, Linear Systems and Linearization, Comparison Functions, Non-autonomous Systems, Linear Time-Varying Systems, and Linearization, Converse Theorems, Boundedness and Ultimate Boundedness, Input-to-State Stability.

Input-Output Stability: L Stability, L Stability of State Models, L2 Gain, Feedback Systems: The Small-Gain Theorem.

Passivity: Memory less Functions, State Models, Positive Real Transfer Functions, L2 and Lyapunov Stability, Feedback Systems: Passivity Theorems.

Feedback Control: Control Problems, Stabilization via Linearization, Integral Control, Integral Control via Linearization, Gain Scheduling.

Feedback Linearization: Motivation, Input-Output Linearization, Full-State Linearization, State Feedback Control.

Nonlinear Design Tools: Sliding Mode Control, Lyapunov Redesign, Back-stepping, Passivity-Based Control, High-Gain Observers.

Books Recommended

1. Hassan K. Khalil, Nonlinear Systems, Second Edition, Prentice Hall Inc., 2002.
2. Ali H. Nayfeh, The Method of Normal Forms, Wiley, 2011.
3. Ali H. Nayfeh, Introduction to Perturbation Techniques, Wiley-VCH Verlag GmbH.
4. D. T. Mook, Ali H. Nayfeh, Nonlinear oscillations, Wiley-VCH Verlag GmbH.
5. Leonard Meirovitch, Methods of Analytical Dynamics, First South Asian Edition, Dover
6. Publications Inc., 2007.

ME-535	Robotics: Mechanics and Control	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the importance of robotics and its impact on human safety, quality of life, economy, environment, etc.; basics of open ended type of Robotic manipulators
CO2	Understanding of kinematics and dynamics of open ended robotic mechanisms; Fixing frames using the Denavit-Hartenberg convention, Jacobian, singularity, Newton-Euler formulations for dynamics of rigid body systems
CO3	Ability to formulate, derive, analyse, design and synthesize kinematics and dynamics of open ended robotic mechanisms
CO4	Understand and apply detailed concepts relating to various actuators, sensors, and their integration with drives and signal conditioning for robotics
CO5	Understanding concepts of feedback control of robotic manipulators based on modern control theory; PID Control; and applying them to Joint control and trajectory control.

Introduction to Robotics

Kinematics and Dynamics of Robotic linkages (open ended type manipulators): Frames, Transformations: Translation and rotation, Denavit-Hartenberg parameters, Forward and Inverse Kinematics, Jacobian, Dynamics: Equations of motion, Newton-Euler formulation.

Sensors and actuators: Strain gauge, resistive potentiometers, Tactile and force sensors, tachometers, LVDT, Piezo electric accelerometer, Hall effect sensors, Optical Encoders, Pneumatic and Hydraulic actuators, servo valves, DC motor, stepper motor, drives.

Control of Manipulators: Feedback control of II order Linear systems, Joint control, Trajectory control, Controllers, PID control.

Books Recommended

1. John J. Craig, Introduction to Robotics: Mechanics and Control, Addison-Wesley, 2005.
2. Tsuneo Yoshikawa, Foundations of Robotics, MIT Press, 1990.
3. Saeed B. Niku, Introduction to Robotics: Analysis, Systems, Applications, Pearson Education Inc., 2001
4. Spong M. W., and Vidyasagar M., Robot Dynamics and Control, John Wiley & Sons, 1989.
5. Murray R. M., et al, A Mathematical Introduction to Robotic Manipulation, CRC Press, 1994.
6. Waldron K. J., and Kinzel G. L., Kinematics, Dynamics and Design of Machinery, John Wiley & Sons, 2004.
7. EroniniUmez-Eronini, System Dynamics & Control, Brooks/ Cole Publishing Company, 1999.
8. Amalendu Mukherjee, Ranjit Karmakar and Arun Kumar Samantaray, Bond Graph in Modeling, Simulation and Fault Identification, I. K. International Publishing House Pvt.

ME-536	Soft Computing Techniques	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To solve differential equations using numerical methods

CO2	Use of MATLAB for numerical analysis and programming
CO3	Use of optimization methods and SIMULINK for programming and scientific computations.

Simple Calculations with MATLAB, Writing Scripts and Functions, Plotting Simple Functions, Loops and Conditional Statements, Root Finding, Interpolation and Extrapolation, Matrices, Numerical Integration

Solving Differential Equations: Some Basics of ODE Integration, Linear PDE, Nonlinear PDE Simulations and Random Numbers.

Optimization Methods: Linear Programming, Dynamic Programming, Network Analysis .

SIMULINK: Introduction to SIMULINK Engineering and Scientific Computations Using SIMULINK, Engineering and Scientific Computations Using SIMULINK

Books recommended

1. S.R. Otto and J.P. Denier, An Introduction to Programming and Numerical Methods in MATLAB. Springer-Verlag London Limited 2005
2. Steven T. Karris , Numerical Analysis Using MATLAB® and Spreadsheets Orchard Publications 2005
3. Sergey E. Lyshevski, Engineering and Scientific Computations Using MATLAB, Pave1 Solin Partial Differential Equations and the Finite Element Method, John Wiley & Sons, Inc., Publication

ME-537	Theory of Elasticity	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to derive the governing equations for 2D and 3D elastic problems
CO2	Be able to analysis of stress and deformation
CO3	To apply the basic field equations of linear elastic solids in various boundary value problems
CO4	To solve these problems with various solution methodologies.

Analysis of Stress: Concept of Stress, Stress Components, Equilibrium Equations, Stress on a General Plane (Direction Cosines, Axis Transformation, Stress on Oblique Plane through a point, Stress Transformation), Principal Stresses, Stress Invariants, Deviatoric Stresses, Octahedral Stresses, Plane Stress, Stress Boundary Condition Problem.

Analysis of Strain: Deformations (Lagrangian Description, Eulerian Description), Concept of Strain, Strain Components (Geometrical Interpretation), Compatibility Equations, Strain transformation, Principal Strains, Strain Invariants, Deviatoric Strains, Octahedral Strains, Plane Strain, Strain Rates.

Stress-Strain Relations: Introduction, One-Dimensional Stress-Strain Relations (Idealized Time-independent and Time dependent stress-strain laws), Linear Elasticity (Generalized Hooke s Law), Stress-Strain Relationships for Isotropic and Anisotropic Materials (Plane stress and Plane Strain).

Basic Equations of Elasticity for Solids: Introduction, Stresses in Terms of displacements, Equilibrium Equations in terms of displacements, Compatibility equations in Terms of Stresses, Special cases of Elasticity equations (Plane Stress, Plane strain, Polar Coordinates), Principle of Superposition, Uniqueness of Solution, Principle of virtual work, Potential and Complementary energy, Variational Principles, St. Venant s Principle, Methods of analysis for Elastic Solutions, Elastic solutions by Displacement and stress Functions, Airys Stress Function (Plane stress, Plane strain, Polar Co-ordinates).

Torsion: Introduction, Circular shaft, Torsion of non-circular cross-section, St. Venant's theory, Warping function, Prandtl s stress function, Shafts of other cross-sections, Torsion of bars with thin walled sections.

Books Recommended

1. Mathematical Theory of Elasticity by I. S. Sokolnikoff.
2. Advanced Mechanics of Materials by Boresi.
3. Theoretical Elasticity by A. E. Green and W. Zerna.
4. Theory of Elasticity, Timoshenko, S.P., and Goodier, J.N., McGraw-Hill.

ME-538	**Theory of Plasticity**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to define stress and strain in 3D system for plastic region with related laws and problems
CO2	Be able to describe mechanism of plastic deformation from fundamentals of material science
CO3	To calculate true stress and strain in plastic deformation
CO4	To understand the physical interpretation of material constants in mathematical formulation of constitutive relationship
CO5	To solve analytically the simple boundary value problems with elasto-plastic properties
CO6	Be able to illustrate slip line field theory and their geometry and property.

Introduction to plasticity: Resolved shear stress & strain, Lattice slip systems, Hardening, Yield surface, Flow rule, Micro to Macro plasticity. Stresses and Strains: The Stress–Strain Behaviour, Analysis of Stress, Mohr's Representation of Stress, Velocity gradient and rate of deformation, Kinematics of large deformation, The Criterion of Yielding, Yielding of materials under complex stress state, Choice of yield function.

Non-Hardening & Elastic-Perfect Plasticity: Classical theories and its application to uniform & non uniform stress states, Hencky vs. Prandtl-Reuss, Elastic–Plastic Torsion and Bending of Beams, Thick walled cylinders.

Theory of the Slipline Field: Formulation of the Plane Strain Problem, Properties of Slipline Fields and Hodographs, Stress Discontinuities in Plane Strain, Construction of Slipline Fields and Hodographs, Analytical and Matrix Methods of Solution, Explicit Solutions for Direct Problems, Some Mixed Boundary-Value Problems, Superposition of Slipline Fields.

Limit Analysis: Collapse of Beams & Structures, Transverse loading of circular plates.

The Flow Curve: Uniaxial tests, Torsion tests, Compression tests, Bulge test, Equations to flow curve, Strain & work hardening hypothesis.

Plasticity with Hardening: Isotropic hardening, Non associated flow rules, Prandtl-Reuss flow theory, Kinematic hardening.

Plastic Instability: Inelastic buckling of struts, Buckling of plates, Tensile instability, Circular bulge instability, Plate stretching.

Books Recommended

1. Theory of Plasticity: J. Chakrabarty.
2. Basic Engineering Plasticity: DWA Rees.

3. The Mathematical theory of plasticity: R.Hill.
4. Continuum Theory of Plasticity: S. Huang.
5. Fundamentals of the Theory of Plasticity: L.M. Kachanov.
6. Plasticity for Engineers: Theory and Applications: C. R. Calladine.
7. Plasticity: Fundamentals and applications, P. M. Dixit and U. S. Dixit
8. Nonlinear Solid Mechanics, D. Bigoni

ME-539	**Theory of Plates and Shells**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to understand the theory, concepts, principles and governing equations of the theory of shells and plates
CO2	Possess the contemporary analytical, experimental and computational tools needed to solve the idealised problem
CO3	To perform critical analysis and design of typical shell structures
CO4	Be able to understand various methods for analyzing grids for roofs and bridges.

Small deflections of transversely loaded plates. Plates equations, boundary conditions. Rectangular and circular plates with different support conditions. General equations of elastic shells in invariant form. Membrane theory, Moment theory. Rotationally symmetric shells. Shallow shell theory. Examples.

Books Recommended

1. J.N. Reddy, "Theory And Analysis of Elastic Plates And Shells" Taylor & Francis 2006.
2. T Krauthammer, E Ventsel, " Thin Plates and Shells: Theory, Analysis, and Applications" Marcel Dekker Inc 2001.
3. S Timoshenko, "Theory of Plates and Shells" McGraw-Hill College 1959.

ME-540	**Tribology**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding of the basic fundamentals of tribology and have a knowledge of surface topography and know how to model a rough engineering surface
CO2	Be familiar with the adhesion theories and effect of adhesion on friction
CO3	Be familiar with the different wear mechanisms and wear models
CO4	Have a knowledge of friction/lubrication mechanisms and know how to apply them to the practical engineering problem.

Introduction: Basics and Fundamentals of Tribology, Nature of Surfaces and their contact; physicomechanical properties of surface layer, Geometrical properties of surfaces, methods of studying surface, contact of smooth surface, contact of rough surfaces.

Friction: Role of friction, laws of static friction, Causes of friction, Adhesion theory, Laws of rolling friction, friction of metals and non-metals, friction measurement.

Wear: Definition of wear, mechanism of wear, Archard's Wear equation, factors affecting wear, wear measurement, wear of metals and non-metals.

Lubricants: Introduction, Types, Functions of lubricants: Types of lubricants and their industrial uses, Selection of lubricants, Properties and tests on lubricants, Analysis of used oils/lubricants, Particle counter, Spectroscopic Oil Analysis, Ferrography.

Lubrication Theories: Lubrication regimes, viscous flow and viscometry, Reynold's equation, hydrodynamic lubrication, hydrostatic lubrication, elasto-hydrodynamic lubrication, boundary lubrication, squeeze films, turbulent lubrication.

Books Recommended

1. Basic Lubrication Theory: Cameron
2. Fundamentals of Tribology: Bharat Bhushan
3. Fundamentals of Tribology: Basu, Sengupta, & Ahuja
4. Fundamentals of Fluid Film Lubrication: Hamrock, Schmid & Jacobson
5. Applied Tribology: Khonsari

ME-541	**Vibration Control**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To study the sources of mechanical vibration and influencing factors affecting level of vibration
CO2	To understand the fundamentals of vibration control
CO3	To learn the methods/techniques for vibration control by damping.

Factors affecting level of vibration, vibration reduction at the source, vibration control by structural design, selection of materials, vibration control by artificial damping, viscoelastic laminate, and material damping, vibration absorbers and auxiliary mass dampers, optimum, tunings and damping application of absorbers, Theory of vibration and shock isolation.

Books Recommended

1. Rao S S, "Mechanical Vibrations", Pearson Education, Delhi (2004).
2. Roger A A, "Fundamentals of Vibrations", Amerind Publisher Company Private Limited, New Delhi (1999).
3. Srinivas P, "Mechanical Vibration Analysis", Tata McGraw Hill Company Limited, New Delhi (1990).
4. Mallik A K, "Principles of Vibrations Control", Affiliated East West Press Private Limited, New Delhi (2000).
5. Lazan B J , "Damping of materials and members in structural mechanics" Pergamon Press 1968.

ME-542	**Vibro-Acoustics**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Learn the basic concepts of noise and acoustics
CO2	Understand the radiation concept of single and multi-degree freedom systems. Learn the coupling of fluid-structure interaction
CO3	Understand the concept of sound radiation by various simple mechanical systems; Learn the basics of Finite element methods
CO4	Learn the basics of mechanical vibrations, modal analysis, and apply finite element method to determine the modal-model of simple structures.

Introduction to Engineering acoustics, wave approach to sound, noise measurement and instrumentation standards, sound pressure, power and intensity, noise radiation from vibrating bodies, single degree of freedom system (SDOF), multiple degree of freedom system (MDOF) vibration in longitudinal bars, fluid structure-acoustic interaction, airborne sound, quantification of sound, random vibrations, flexural vibration of beams, plates and shells, sound sources, room acoustics, sound structure, statistical energy analysis(SEA), Introduction about experimental modal analysis, finite element method approach to predict the mode shapes of a beam, plate or a three dimensional vibro-acoustic cavity.

Books Recommended

1. M. C. Junger, D. Feit, Sound, Structures and Their Interaction, The MIT Press (December 30, 1972).
2. F. J. Fahy, Sound and Structural Vibration: Radiation, Transmission and Response, cademic Press (January 28, 1987).
3. L. Cremer, M. Heckl, B.A.T. Petersson, Structure-Borne Sound: Structural Vibrations and Sound Radiation at Audio Frequencies, Springer, 3rd ed. edition (March 14, 2005).
4. R. H. Lyon, R. G. Dejong, Theory and Application of Statistical Energy Analysis, R.H. Lyon Corp (January 1, 1995).
5. R.H. Lyon, Machinery Noise and Diagnostics. Boston:Butterworths (1986)
6. E. Skudrzyk, Simple and Complex Vibratory Systems (Hardcover), Univ of Pennsylvania Press (June 1968).

ME-543	Viscoelasticity	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of mathematics, science and engineering
CO2	To apply and integrate knowledge of viscoelastic behaviour to solve real life problems
CO3	Ability to learn the basics of viscoelasticity.

Viscoelastic Models & Hereditary Integrals: The basic elements: spring and dashpot, Maxwell fluid and Kelvin solid, Unit step function, Dirac function, Laplace transformation, Kelvin chains and Maxwell models, Creep compliance, relaxation modulus, Hereditary integrals, Integral equations.

Viscoelastic Beams: The correspondence principle, Hereditary integrals, Structures made of two materials, Solution of the integral equation, Differential equation of the beam, General correspondence principle, Beam on Continuous Support: Differential equation, A simple example, Concentrated load, Moving load on an infinite beam, Rolling friction.

Vibrations: Complex compliance, Dissipation, Application to specific materials, Relations between compliances, The simple spring-mass system, Forced vibrations.

Wave Propagation & Buckling of Columns: The differential equation, The wave front, Maxwell material, Viscous material, Oscillatory load, Bar with elastic restraint, The concept of stability, Inverted pendulum, Elastic column, Viscoelastic column

Viscoelasticity in Three Dimensions: Analysis of stress and strain, The viscoelastic law, Uni -axial stress, Viscoelastic cylinder in a rigid die, Correspondence principle, Two-dimensional problems, Thick-walled tube.

Books Recommended

1. Viscoelasticity by Wilhelm Flugge, Springer
2. Theory of Viscoelasticity by R. M. Christensen, Dover publications.

ME-544	Wave Propagation in Solids	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to derive the governing equations for Navier’s equation of motion problems
CO2	Be able to analysis of stress wave in 1-D problem

CO3	To apply the basic stress wave equation in various boundary value problems
CO4	To solve half-space problems (Rayleigh waves).

Review of elasticity: Navier's equation of motion, Boundary and initial conditions.

Longitudinal and torsional waves: 1-D. D'Alembert's solution.

Method of characteristics: Radiation conditions; Wave packets; Group velocity.

Three-dimensional waves: Helmholtz decomposition, Dilatational and shear waves, Plane waves, Harmonic waves. Slowness diagrams.

Reflection and transmission: Reflection and transmission of P, SV, SH waves across interface; continuity conditions; Snell's law; Reflection and refraction at interfaces.

Half-space problems: Half-space problems: Rayleigh waves; Suddenly applied uniform normal pressure with zero body force; Cagniard de Hoop method; Buried load problem; Scattering from crack tips in mode III.

Waveguides:1-D waves; Dispersion; String on elastic foundation; Cut-off frequency; 2-d waves; Thin plates (Kirchhoff's theory); Lamb waves; Love waves; Rods; Pochammer-Chree equation.
Waves in anisotropic media and crystals

Experimental characterization: Kolsky bar

Advanced topics: One from: Plastic waves/Layered media/Visco-elastic waves/Shock waves/ Nonlinear waves/Thermal waves/Waves in discrete media/Scattering from mode I and II cracks.

Books Recommended

1. Achenbach J.D., Wave Propagation in Solids, Elsevier Science Publishers, 1975.
2. Graff K. F., Wave Motion in Elastic Solids, Dover Publications, 1991.
3. Brekhovskikh and GoncharovV., Mechanics of Continua and Wave Dynamics, L. Springer-Verlag, 1985.
4. MiklowitzJ., The Theory of Elastic Waves and Waveguides, North-Holland Publishing Company, 1978.

ME-545	**Welding and Allied Processes**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding of the basic fundamentals of joining technology and have a knowledge of various joining processes
CO2	To attain the knowledge of different power sources used along with the VI characteristics
CO3	To understand the chemistry of fluxes, its reactions to the molten metal and various consumables used in welding/ joining technology
CO4	To attain the knowledge of various joining processes, their application, advantages and limitations.

Introduction: Introduction to joining technology, General survey and classification of welding processes, Safety and hazards in welding, Physics of the welding arc and arc characteristics, Metal transfer & its importance in arc welding, Various forces acting on a molten droplet and melting rates.

Power sources for arc welding: Power sources for arc welding, classification of power sources, characteristic curves.

Welding consumables: Fluxes, gases and filler materials for various welding processes.

Welding Processes and their Applications: SMAW, SAW, GTAW and related processes, GMAW and variants, PAW, Gas welding, Soldering, Brazing and diffusion bonding, Thermal cutting of metals, Surfacing and spraying of metals, Resistance welding processes: spot, seam, butt, flash, projection, percussion etc, Thermit welding, Electro-slag and electro-gas welding, Solid-state and radiant energy welding processes such as EBW; LBW; USW, Explosive welding; Friction welding etc, Welding of plastics, Advances, challenges and bottlenecks in welding.

Books Recommended

1. Lancaster J F, "The Physics of Welding", Pergamon Press (1984)
2. Little R F, "Welding and Welding Technology", McGraw Hill Co (2001)
3. Nadkarni S V, "Modern Arc Welding Technology", Ador Welding Ltd (2008)
4. Davies A C, "Welding" , Cambridge University press, (2005)

CURRICULUM

July 2019 admission onwards

APPROVED BY

BOARD OF STUDIES (BOS)
MEETING, February 20, 2019

MTech in Thermal Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

Dr B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY, JALANDHAR

Phone: 0181-2690301, 02 (Ext. 2101, 2104), Fax: 0181-2690932 Website: www.nitj.ac.in

<u>Annexure-F</u>

DR B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY

JALANDHAR
Teaching Scheme and Syllabus
of
Regular MTech in Thermal Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

SCHEME OF INSTRUCTION AND DETAILED SYLLABI

MASTER OF TECHNOLOGY IN THERMAL ENGINEERING

EFFECTIVE FROM JULY, 2019 ONWARDS

Course Scheme for MTech in Thermal Engineering

FIRST SEMESTER				
S.No.	**Course No.**	**Subjects**	**L-T-P**	**Credit**
1.	MA-553	Computational Methods in Engineering	3-0-0	3
2.	ME-551	Advanced Thermodynamics	3-0-0	3
3.	ME-553	Advanced Heat Transfer	3-0-0	3
4.	ME-555	Computational Fluid Dynamics	3-0-0	3
5.	ME-XXX	Programme Elective-I	3-0-0	3
6.	ME-561	Advanced Heat Transfer Lab	0-0-3	2
7.	ME-563	Computation and Simulation Lab	0-0-3	2
		Total	**15-0-6**	**19**

SECOND SEMESTER				
S.No.	**Course No.**	**Subjects**	**L-T-P**	**Credit**
1.	ME-552	Advanced Fluid Mechanics	3-0-0	3
2.	ME-554	Combustion and Emissions in IC Engine	3-0-0	3
3.	ME-556	Design and Optimization of Thermal Systems	3-0-0	3
4.	ME-XXX	Programme Elective-II	3-0-0	3
5.	ME-XXX	Programme Elective-III	3-0-0	3
6.	ME-562	Thermal Comfort and Building Energy Simulation Lab	0-0-3	2
7.	ME-564	Engines and Unconventional Fuels Lab	0-0-3	2
		Total	**15-0-6**	**19**

THIRD SEMESTER				
S.No.	**Course No.**	**Subject**	**L-T-P**	**Credit**
1.	ME-600	Project Work for MTech Dissertation, Part-I	0-0-12	6
2.	ME-601	Independent Study	0-0-6	3
3.	ME-558	Heat Exchangers	3-0-0	3
4.	ME-XXX	Programme Elective-IV	3-0-0	3
		Total	**6-0-18**	**15**

FORTH SEMESTER				
S.No.	**Course No.**	**Subject**	**L-T-P**	**Credit**
1.	ME-600	Project Work for MTech Dissertation, Part-II	0-0-24	12
		Total	**0-0-24**	**12**

Summary				
Semester	**I**	**II**	**III**	**IV**
Semester-wise total credit	**19**	**19**	**15**	**12**
Total credits	**65**			

Credit Distribution for MTech in Design Mechanical Engineering					
Category	**Sem - I**	**Sem - II**	**Sem - III**	**Sem - IV**	**Total No. of Credits to be earned**
Core Courses	**9**	**9**	**-**	**-**	**18**
Electives	**6**	**6**	**6**	**-**	**18**
Lab Courses	**4**	**4**	**-**	**-**	**8**
Seminar	**-**	**-**	**3**	**-**	**3**
Dissertation	**-**	**-**	**6**	**12**	**18**
Total	**19**	**19**	**15**	**12**	**65**

Programme Electives				
S.No.	**Course Code.**	**Subjects**	**L-T-P**	**Credit**
1	ME-565	Advanced IC Engines	3-0-0	3
2	ME-566	Advanced Power Plant Cycles	3-0-0	3
3	ME-567	Advanced Steam Power Plants	3-0-0	3
4	ME-568	Aerodynamics	3-0-0	3
5	ME-569	Alternative Fuels for IC Engines	3-0-0	3
6	ME-570	Applied Combustion	3-0-0	3
7	ME-571	Combustion Generated Pollution and Control	3-0-0	3
8	ME-572	Cryogenic Engineering	3-0-0	3
9	ME-573	Exergy Analysis of Thermal and Energy System	3-0-0	3
10	ME-574	Experimental Methods and Analysis	3-0-0	3
11	ME-575	Gas Dynamics	3-0-0	3
12	ME-576	Gas Turbines and Jet Propulsion	3-0-0	3
13	ME-577	Measurements in Thermal Engineering	3-0-0	3
14	ME-578	Microscale Transport Phenomena	3-0-0	3
16	ME-579	Multi-Phase Flow and Heat Transfer	3-0-0	3
17	ME-580	Optimization Theory	3-0-0	3
18	ME-581	Photovoltaic Cell and its Applications	3-0-0	3
19	ME-582	Refrigeration Systems and Components Design	3-0-0	3
20	ME-583	Renewable Energy	3-0-0	3
21	ME-584	Solar Passive Design and Sustainable Buildings	3-0-0	3
22	ME-585	Thermal Behaviour of Advanced Materials	3-0-0	3
23	ME-586	Turbomachinery	3-0-0	3
24	ME-587	Waste Heat Utilization and Polygeneration	3-0-0	3

First Semester

MA-553	Computational Methods in Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the stepwise procedure to completely solve a fluid dynamics problem using computational methods
CO2	Ability to solve ODE problems using power series solutions
CO3	Ability to solve PDE using various analytical methods
CO4	Development of a clear understanding on Tensors, their operation and applications.

In relation to mechanical engineering applications, such as, heat transfer, fluid mechanics, vibrations, dynamics and others, the following topics will be covered:

Partial differential equations: Characteristics and classification of 2nd order PDEs. separation of variables special functions, Eigen function expansions, Fourier integrals and transforms, Laplace transforms, methods of characteristics, self-similarity.

Linear algebra: Matrix theory, solution of linear system of algebraic and differential equations; round-off errors, pivoting and ill-conditioned matrices. Eigenvalues and eigenvectors.Unitary, Hermitian and normal matrices.

Numerical Methods: Lagrange interpolation, splines, integration – trapezoid, Romberg, Gauss, adaptive quadrature. Explicity and implicity methods, multi-step methods, Runge-Kutta and predictor-corrector methods, boundary value problems, eigenvalue problems, systems of differential equations, stiffness.Accuracy, stability and convergence.Alternating direction implicity methods.Non-linear equations.

Books Recommended

1. Ames W F, “NumericalMethods for Partial Differential Equations”, 3rd Edition, Academic Press, New York (1992).
2. Dahlquist G and Björck A, “Numerical Methods”, Prentice-Hall, NJ (1974).
3. Jain M K, Iyengar S R K. and Jain R K, “Numerical Methods for Scientific and Engineering Computations”, 4th Edition New Age International (P) Limited, Publishers, New Delhi (2003).
4. Shampine L F, “Numerical Solution of Ordinary Differential Equations”, Chapman and Hall, New York (1994).
5. Kreyszig, E., "Advanced Engineering Mathematics", 8th Ed, John Wiley, Singapore, 2002.

ME-551	Advanced Thermodynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Ability to solve thermodynamics relations and obtain thermodynamic efficiency
CO2	Ability to analyze problems persisting with real and ideal gas
CO3	Ability to solve stability and phase relations
CO4	Understanding of the concept of reactive mixtures.

Recapitulation of fundamentals.The two laws of thermodynamics–Caratheodory’s formulation, analysis of typical simple closed systems, analysis of open systems–exergy analysis.Multicomponent systems–concepts of fugacity, chemical potential.General conditions for thermodynamic equilibrium–instability of thermodynamic equilibrium and phase transition.Thermodynamics of reactive mixtures.Elements of irreversible thermodynamics.

Books Recommended

1. Cengel& Boles, “ Thermodynamics-An Engineering approach”.5th Ed, Tata McGraw Hill
2. Winterbone, Desmond E, “ Advanced Thermodynamics for engineers”,1997,Elsevier
3. Annamalai, Puri, Ishwar.K. “Advanced Thermodynamics Engineering”2002,CRC Press.
4. Nag,P.K., “ Engineering Thermodynamics”,4th ed., Tata Mcgraw Hill.

ME-553	Advanced Heat Transfer	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand both the physics and the mathematical treatment of the advanced topics pertaining to the modes of heat transfer
CO2	Ability to formulate heat transfer conduction and radiation problems using ODE's and PDE's and obtain analytical solution
CO3	Apply principles of heat transfer to develop mathematical models for uniform and non-uniform fins
CO4	Analyze free and forced convection problems involving complex geometries with proper boundary conditions
CO5	Apply the concepts of radiation heat transfer for enclosure analysis.

Review of basic heat transfer, Introduction to Conduction, convection and radiation heat transfer, 1-D Steady State Heat Conduction, Fins with variable cross-section, generalized equation for fins, Fins of parabolic and triangular profiles, Transient in lumped systems, Multi-Dimensional Conduction, Analytical and numerical methods for solving multi-dimensional problems, Graphical method, Conduction shape factor, Analogical method, Relaxation Technique, Finite Difference method, Convective Heat Transfer, Momentum and Energy Integral Equation, Thermal and hydrodynamic boundary layer thickness, Heat transfer in a circular pipe in laminar flow when constant heat flux and constant wall temperature to the wall of the pipe, convection correlations for turbulent flow in tubes, Flow over cylinders and spheres, Flow across tube bundles/banks, Natural convection, Heat transfer from a vertical plate using the Integral method, Free convection in enclosed spaces, Mixed convection, Introduction to Boiling and Condensation Heat Transfer,Thermal radiation, Review of basics of surface radiation, non gray body, radiation shape factor, Hottel's Crossed String Method for finding shape factor, Radiosity and irradiation formulation, radiation shield and Gas radiation, Heat Exchangers, Review of basic concepts, Tubular and plate type heat exchanger, Overall heat transfer coefficient, LMTD, correction factor, Effectiveness, Introduction to design of heat exchangers.

Books Recommended

1. M.N. Ozisik, *Basic Heat Transfer*, Mc-Graw Hill, Inernational edition, 1988
2. J.P. Holman, *Heat Transfer*, McGraw Hill, 10th edition, 2010
3. F. Incropera, and D. J. Dewitt, *Introduction to Heat Transfer* –Wiley & Sons Inc., 6th edition,2010.
4. F. Kreith, *Principles of Heat Transfer*, Harper & Row, New York, 4th edition, 1986.
5. Gupta and Prakash, *Engineering Heat Transfer*, New chand& Bros, 4th edition
6. Bejan, *Convective Heat Transfer*, J. Wiley & Sons, 2nd edition, 1995.
7. S.P. Venkateshan, *Heat Transfer*, Ane Publication, 2009.
8. P.S.Ghoshdastidar, *Heat Transfer*, Oxford, Univ press, 2nd edition, 2012.
9. Domkundwar and Arora, *A Course in Heat and Mass Transfer*, DhanpatRai& Sons, 7th edition 2008.

ME-555	Computational Fluid Dynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand CFD as a tool, need for development and analysis in fluid dynamics and heat transfer problems
CO2	Handle ordinary and partial differential equations, and their linearization using CFDtechniques
CO3	Understand basic concept of FVM and its implementation on heat transfer and fluid dynamics problems
CO4	Develop codes for various fluid dynamics and heat transfer problems based on CFD.

Review of basic fluid mechanics and the governing Navier-Stokes equations, Techniques for solution of PDEs – finite difference method, finite element method and finite volume method, Finite volume (FV) method in one dimension, Differencing schemes, Steady and unsteady calculations, Boundary conditions, FV discretization in two and three dimensions, Simple algorithm and flow field calculations, variants of SIMPLE, Turbulence and turbulence modeling, illustrative flow computations, Commercial softwares FLUENT and CFX – grid generation, flow prediction and post-processing.

Books Recommended

1. S V Patankar, *Numerical Heat Transfer and Fluid Flow*, McGraw Hill, NY, 2005.
2. John Anderson, "*Computational Fluid Dynamics*", McGraw-Hill Publication, First edition,1995
3. W M Kays and M E Crawford, *Convective Heat and Mass Transfer*, Mc-Graw Hill, New York 1993.
4. F M White, *Viscous Fluid Flow* by, Mc-Graw Hill, New York, 2nd Ed. 1991.
5. Robert Siegel and John Howell, *Thermal radiation Heat Transfer*, 4th Edition, Taylor and Francis NY, 2002.

ME-561	Advanced Heat Transfer Lab	(0 0 32)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand in utilizing the lab equipments for research purpose. Ability to conduct experiments and validate with the theoretical/analytical results
CO2	Understand heat transfer during charging and discharging of PCM in thermal energy storage system
CO3	Understand the flow patterns across different types of bodies using CCD camera. Understanding of thermal and hydrodynamic boundary layer for flow over surfaces
CO4	Understand the performance of different type of heat exchanger, spray cooling on a flat surface. Understanding of statistical analysis of the results.

List of Experiments

1. Evaluation of effect of surface roughness on heat transfer characteristics for absorber plate of solar flat plate collector. Perform statistical analysis of the results.
2. Evaluate the heat transfer characteristics for swirling flames impinging on the flat surface. Perform statistical analysis of the results.
3. Evaluate heat transfer during charging and discharging of PCM in thermal energy storage system.
4. Evaluate the thermal efficiency during charging, storing and discharging the PCM in thermal energy storage system and further evaluate the overall system thermal efficiency.
5. Evaluate the flow patterns across different types of streamline bodies and bluff bodies at different temperatures using CCD camera.
6. Evaluate the thermal and hydrodynamic boundary layer for flow over surfaces.
7. Evaluate the performance of shell and tube conventional and compact type heat exchanger.
8. Evaluate the performance of the spray cooling on a flat surface.

ME-563	Computation and Simulation Lab	(0 0 32)

Course Outcomes: At the end of the course the student will be able to:

CO1	Formulation and solution of problems in fluid flow and heat transfer
CO2	Understand the discretization of differential equations, provide boundary conditions and obtain numerical solution for fluid and heat transfer problems
CO3	Develop codes for numerical methods to solve 1D and 2D heat conduction and convection problems

CO4	Use commercial software like ANSYS, open foam etc. for solving real life engineering problems.

List of Experiments

1. To study 2D Laminar and turbulent flow problems using CFD codes/tools and validation with Blasius equation.
2. To study formation of flat plate boundary layer (2D) using CFD codes/tools and validation the results with analytical correlations.
3. To study the turbulent forced convection problem in a pipe using CFD codes/tools considering top and bottom walls as a constant wall temperature boundary condition and validation the results with Dittus-Boelter equation.
4. To study flow past a cylinder in steady state using CFD Code/tools.
5. To study flow past a cylinder in unsteady state using CFD Code/tools.
6. To study compressible Flow in a Nozzle using CFD Code/tools.
7. To study the free fall of droplet using CFD Code/tools and validate results with High speed camera images.
8. To study the rise of the bubble using CFD Code/tools and validate results with High speed camera images.
9. To study two phase flow in a microchannel with micro cavity using CFD Code/tools and validate results with High speed camera images.

Second Semester

ME-552	Advanced Fluid Mechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Ability to apply knowledge of fluid mechanics in research and technology
CO2	To enable the students to learn about the mathematical modeling techniques for fluid mechanics problems
CO3	To enable the students to understand the importance of analytical approximate solutions
CO4	Ability to understand and solve complex turbulent flow problems.

Review of basic laws of fluid flow in integral and differential form, kinematics, Ideal fluid flow. Newtonian fluid flow and applications, Creeping flow, Boundary layer theory, Transition and turbulence turbulent boundary layer Fundamentals of compressible flows Modelling and dimensional analysis.

Books Recommended

1. Douglas J F. Gasionckw, and Swaffield JP “Fluid Mechanics” 3rd edition AddisionWesley Longman, IncPitman, 1999.
2. Pao H F Richard “Fluid Mechanics” John Wiley and Sons. 1995
3. Kumar DS “Fluid Mechanics and Fluid Power Engineering” 6th edition SK KatariaandSons, Delhi. 1998.
4. Streeter V L and Wylie E B “Fluid Mechanics” McGraw Hill International.
5. Bansal R K “ A text book of Fluid mechanics and Hydraulic Machines” 8th edition, LaxmiPublications Ltd. New Delhi, 2002.
6. Mohanty A K, “Fluid Mechanics”, 2nd Edition Prentice Hall of India Private Limited, NewDelhi, 2002.

ME-554	Combustion and Emissions in IC Engine	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To study the various properties of IC engine fuels and determination of air required for combustion
CO2	To study the various stages of combustion in SI and CI engines and understand the normal and abnormal combustion phenomena
CO3	To study the kinetics of CO, HC, NOx, their measurement and emission control strategies to conform to legislation standards
CO4	To study various alternative fuels for IC engines and their effect on performance and emission characteristics.

Fuels: Important qualities of SI and CI engine fuels and their ratings. Combustion of Fuels: Heating values of Fuels – SI engine fuels – CI engine fuels – Determination of minimum air required for combustion, conversion of volumetric analysis to mass analysis, Determination of air supplied from volumetric analysis of Dry flue gases,

Combustion in SI Engines: Stages of combustion, Flame front propagation– Factors influencing flame speed, Thermodynamic analysis:Burned and unburned mixture states. Analysis of cylinder pressure data, Combustion process characterization, Flame structure and speed; flame structure, laminar burning speeds, flame propagation relations, Cyclic variations in combustion, partial burning and misfire: definitions, causes of cycle – by – cycle and cylinder to cylinder variations, partial burning, misfire and engine stability. Spark Ignition: Ignition fundamentals, conventional ignition systems, alternative ignition systems, alternative ignition approaches, Abnormal Combustion: knock and surface ignition, knock fundamentals, fuel factors.

Combustion in CI Engines: Stages of combustion in CI Engine – Ignition delay – Factors effecting ignition delay, physical properties affecting delay, Types of diesel combustion systems: Direct injection systems, indirect injection systems, Analysis of cylinder pressure data; combustion efficiency, DI engines, IDI engines, Fuel spray behavior: Fuel injection, overall spray structure, atomization, spray penetration, droplet size distribution and spray evaporation, Ignition delay: definitions and discussion, fuel ignition quality, auto ignition fundamentals, effect of fuel properties.

Emission and Control: Emission of various pollutants from the engine, Kinetics of NOx, HC and CO formation in SI and CI Engines, Measurement of Emissions, Exhaust gas treatment. Emission Standards

Alternative Fuels – Alcohols **-** CNG – LPG – Hydrogen **-** Biodiesels – Biogas **-** Dual fuel operation. Performance and Emission Characteristics of SI and CI Engines using these alternatefuels.

Books Recommended

1. John. B.Heywood, *Internal Combustion Engine Fundamentals*, McGraw Hill, 1988.
2. E.F. Obert, *Internal Combustion Engine and Air Pollution*, Harper and Row Publishers, 1973.
3. V.L. Maleeve, *Internal Combustion Engines*, McGraw Hill Book Company, 1945.
4. Colin R.Ferguson and Allan T.Kirkpatrick, *Internal Combustion Engines*, Wiley publishers, 2000.
5. Mathur& Sharma, *Internal Combustion Engines*, Dhanpatrai Publishers. 2006.
6. V.Ganesan, *Internal Combustion Engines*, Tata McGraw Hill, 2003.
7. H.N.Gupta, *Fundamentals of Internal Combustion Engines*, PHI, New Delhi, 2006.
8. PulkRabek W W, *"Engineering Fundamentals of Internal Combustion Engine",* Pearson EducationNew Delhi (2003).

ME-556	Design and Optimization of Thermal Systems	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the various Thermal systems encountered in Engineering along with the importance of their associated parameters
CO2	To apply the various concepts learnt in the subjects of Thermodynamics, Fluid Mechanics, Heat Transfer and Applied Mathematics to predict and simulate the performance of Thermal systems
CO3	To understand the different Optimization techniques and develop the skills to Model and analyze the various Thermal systems
CO4	To develop skills to solve single as well as Multivariable optimization problems.

Introduction to Design and Analysis, and Project Initiation, Review of Fluid Mechanics, Thermodynamics & Heat transfer, System identification and description & component design: Heat exchangers, Prime movers, System Design and Optimization Techniques and Economic Evaluation, Engineering economics.

Books Recommended

1. Stoecker, W., Design of Thermal Systems, McGraw-Hill
2. Burmeister, L.C., Elements of Thermal-Fluid System Design, 1998,Prentice Hall
3. Jaluria, Y., Design and Optimisation of Thermal Systems, 2007,McGraw-Hill,
4. Janna, W.S., Design of Fluid Thermal Systems, 1993,PWS-Kent Publishing, 1993.

ME-562	Thermal Comfort and Building Energy Simulation Lab	(0 0 3 2)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the basic principles and fundamentals of mechanical engineering systems in the building engineering science
CO2	To understand basic principle of engineering to design and analyze various types of mechanical systems in built environment
CO3	To provide a bird eye view and holistic approach of modeling and simulation of mechanical systems for energy efficiency and sustainable development.

List of Experiments

1. PV Solar systems modeling and analysis
2. Introduction to building energy simulation tools i.e. e-Quest, Energy plus, TRNSYS
3. Modeling techniques, validation of simulation model
4. Simulation for energy efficiency of buildings
5. Simulation for ECBC code compliance by whole simulation method

ME-564	Engines and Unconventional Fuels Lab	0 0 3 2)

Course Outcomes: At the end of the course the student will be able to:

CO1	To make the students understand the functioning of various sensors and actuators in an Engine
CO2	To make students understand the effect of EGR on NOx emissions
CO3	To make the students understand the effect of various engine parameters on performance and combustion characteristics
CO4	To enable the students understand the determination of Uncertainty in measurements.

List of Experiments

1. To measure the properties of the fuel
   a. Acid Number
   b. Viscosity of oils/ liquid fuels
   c. Density and specific gravity of oils/ liquid fuels
2. Study of Performance characteristics of a Single Cylinder DI engine and its comparison with similar CRDI engine
3. Study of Various sensors and actuators required for an open ECU based CRDI engine.
4. Study of Performance and combustion characteristics of multicylinder CRDI engine.
5. Utilization of Exhaust Gas Recirculation (EGR) for reduction of NOx emissions in compression ignition engine.
6. To perform an Uncertainty analysis on engine performance and combustion parameters.

Third Semester

ME-558	Heat Exchangers	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To introduce basic heat transfer mechanisms in heat exchangers; Classification of Heat Exchangers
CO2	To understand and apply the different heat transfer and pressure drop correlations for single and two phase flows
CO3	To understand the concepts related to Thermal and Hydraulic designs of heat exchangers and perform calculations for the design of Double pipe, Shell and Tube and compact Heat Exchangers
CO4	To understand the concepts of Fouling and its impact on thermal design of heat Exchangers
CO5	To introduce the various commercial soft wares available to design the various types of Heat Exchangers.

Applications.Basic design methodologies – LMTD and effectiveness-NTU methods. Overall heat transfer coefficient, fouling. Correlations for heat transfer coefficient and friction factor. Classification and types of heat exchangers and construction details. Design and rating of double pipe heat exchangers, compact heat exchangers, plate and heat pipe type, condensers, cooling towers. Heat exchanger standards and testing, Heat transfer enhancement and efficient surfaces.Use of commercial software packages for design and analysis, optimization.

Books Recommended

1. Kays and London, “Compact Heat Exchangers”, McGraw Hill.
2. Hesselgreaves, “Compact Heat Exchangers Selection, Design & Operation”, Pergamon.
3. Shah, R.K. &Sekulic D.P, “Fundamentals of Heat Exchanger Design”, John Wiley & Sons.
4. Kakac& Liu, “ Heat Exchangers-Selection, Rating and Thermal Design”, 2nd ed.,CRC Press

Programme Electives

ME-565	Advanced IC Engines	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To expose the students to various air standard and fuel air cycles and the reasons for the deviation of real cycles from ideal cycles
CO2	To enable the students to do the performance analysis of IC Engine and justify the suitability of IC Engine for different applications
CO3	To study the new trends in engines with an aim to improve the performance and emission characteristics
CO4	To study the recent trends in Engine Management System

Cycle Analysis: Otto, diesel, dual, Sterling and Brayton cycles, comparison of air standard, fuel air and actual cycles, simple problems on the above topics.

Measurement and Testing: Measurement of IP. FP, BP, friction fuel consumption, air consumption, speed, emission.Performance Characteristics of SI and CI Engines, Engine performance maps, Heat Balance sheet.

Special Types of Engines: Introduction to working of stratified charged engines, Wankel engine, variable compression engine, Surface ignition engines, free piston engines, Current engines and future trends (e.g. Convergence of SI and CI engine technology, Control developments, fuel quality), Effect of air cleaners and silencers on engine performance.

Recent Trends: Homogeneous Charge Compression Ignition Engine, Lean Burn Engine, Stratified Charge Engine, Surface Ignition Engine, Four Valve and Overhead cam Engines, Electronic Engine Management, Common Rail Direct Injection Diesel Engine, Gasoline Direct Injection Engine, Data Acquisition System –pressure pick up, charge amplifier PC for Combustion and Heat release analysis in Engines.

Electronic Engine Management: Computer control of SI & CI engines for better performance and low emissions, closed loop control of engine parameters of fuel injection and ignition

Books Recommended

1. Heinz Heisler, 'Advanced Engine Technology," SAE International Publications,USA,1998 Ganesan V. "Internal Combustion Engines" , Third Edition, Tata Mcgraw-Hill ,2007
2. Tom Denton. "Automobile Electrical and Electronic Systems", Elsevier, 2004
3. John B Heywood," Internal Combustion Engine Fundamentals", Tata McGraw-Hill, 1988
4. Richard Stone. "Introduction to Internal Combustion Engine", Society of Automotive Engineers Inc 1999
5. Hua Zhao, NicosLadommatos. "Engine combustion instrumentation and diagnostics", Society of Automotive Engineers, 2001
6. Robert Bosch GmbH."Bosch Automotive Electrics and Automotive Electronics: Systems and Components, Networking and Hybrid Drive", Springer View.

ME-566	Advanced Power Plant Cycles	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To acquire the knowledge on advanced power plant cycles such as combined cycle, Kalina cycle, zero emission cycle (hydrogen-oxygen cycle), nuclear cycle etc
CO2	To estimate irreversibilities of the power plant components for exergy analysis

CO3	To simulate and optimize the real cycles
CO4	To analyse the power plant at off-design conditions
CO5	To distinguish between various power generation units and choose one that meets desired economic, environmental and social requirements.

Review of various ideal cycles–Rankine and Brayton–and fuel-air cycles.Thermodynamics optimization of design parameters. Real cycle effects–internal and external irreversibilitites, pressure drops, heat loss, condenser air leakage, fouling of heat transfer surfaces, combustion losses–and their impact on the thermodynamic cycle. Optimization of real and double reheat cycles. Analysis of off-design performance.Combined cycles–ideal and real cycles–thermodynamic analysis.Design of alternate schemes for combined cycles– single, dual and triple pressure cycles, and their optimization. Retrofit of ageing power plants. Parametric analysis–effects of gas and steam cycle variables. Binary vapour and Kalinacycles.Thermochemical and H2-O2 cycles.Cycles for nuclear power plants (PWR, BWR, PHWR, FBR). All simulations will involve extensive use of numerical techniques as part of laboratory work.

Books Recommended

1. Wiesman J and Eckart R, “Modern Power Plant Engineering”, Prentice Hall,New Delhi ,1985.
2. Nag P K, “Power Plant Engineering”, Tata McGraw Hill,New Delhi ,1998.
3. Kostyuk.A and Frolov V, “Steam and Gas Turbines”, Mir Publishers, Moscow ,1988.
4. Aschner F S, “Planning Fundamentals of Thermal Power Plants”, John Wiley ,1978.
5. Eastop T D and McConkey, “Applied Thermodynamics”, Longman Scientific and Technical, 1986.

ME-567	**Advanced Steam Power Plants**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply the knowledge of advanced thermal power plants from simple cycle to supercritical cycle
CO2	To design the components in thermal power plants and cogeneration plants such as boiler, condenser and other heat exchangers
CO3	To conduct the energy auditing and exergy evaluation
CO4	To analyse latest power augmentation techniques in thermal power plants
CO5	To know about the kind of boilers being used in various industries and their applicability.

Thermal Power Plant Engineering, Energy sources and scenario – Power Plant Cycles – Reheat – Regenerative, Supercritical -Coupled and combined – Cogeneration Plants, Exergy analysis of power plant cycles, Coal, its properties, combustion, Analysis and sizing of Power Plant Components: Steam generator, Condenser, Cooling tower and other heat exchangers, Power plant economics, energy audit. Recent trends in power production.

Books Recommended

1. R.W. Haywood, *Analysis of Engineering Cycles*, Pergamon Press, 1975.
2. A.W. Culp, *Principles of Energy Conversion*, McGraw Hill, 1979.
3. M.M. Elwakil, *Power Plant Technology*, McGraw Hill, 1984.
4. T.D. Eastop and A.McConkey, *Applied Thermodynamics*, ELBS, 1986.
5. P.K.Nag, *Power Plant Engineering*, Tata McGraw Hill, 2000.
6. J.Weisman, and R.Eckart, *Modern Power Plant Engineering*, Prentice Hall, 1985.

ME-568	Aerodynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To develop knowledge in the field of potential flow theory and their applications in aerodynamics problems
CO2	To develop ability to model lift for flow over arbitrary cylinders
CO3	Understanding to model lift over airfoil using thin airfoil theory and Kutta-Jowkowski law
CO4	Understanding of laminar and turbulent boundary layer theory.

Aerodynamic forces and moments; continuity, momentum and energy equations; Inviscid incompressible flow – incompressible flow in a low speed wind tunnel, source and doublet flows, nonlifting flow over a circular cylinder, Kutta-Joukowski theorem; Incompressible flow over airfoils and finite wings – Kutta condition, Kelvin's circulation theorem, Biot-Savart law, Helmholtz vortex theorem, Prandtl's classical lifting line theory; Thin aerofoil theory; Three dimensional source and doublet; Inviscid compressible flow – normal and oblique shocks, expansion waves, supersonic wind tunnels; Elements of hypersonic flow, Newtonian theory; Equations of viscous flow; Laminar and turbulent boundary layers; Panel methods in aerodynamics.

Books Recommended

1. J.D. Jr.Anderson, *Fundamentals of Aerodynamics*, McGraw Hill
2. J.J. Bertin, *Aerodynamics for Engineers*, Pearson Education, 2002.
3. E.L. Houghton and N.B. Carruthers, *Aerodynamics for Engg. Students*, Arnold Pub., 1988.
4. A.M. Kuethe, and C.Y. Chow, *Foundations of Aerodynamics*, Wiley, 1998.
5. L.J. Clancy, *Aerodynamics*, Himalayan Books, 1996.

ME-569	Alternative Fuels for IC Engines	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Interpret and distinguish between the different types of conventional and non-conventional fuels
CO2	Demonstrate the utilization of synthetic and substitute fuels for practical applications
CO3	Describe various parameters that are utilized to characterize alternative fuels and its combustion process
CO4	Solve renewable energy related problems with knowledge in fossil fuels and alternative fuels
CO5	Demonstrate knowledge in production methods of different alternative fuels
CO6	Select from different alternative fuels available for specific potential applications
CO7	Understand the socio-economic, environmental impacts, limitations and applications of alternative fuels.

Hydrocarbon fuels: Crude petroleum oil and its refining, products of refining, availability of hydrocarbon fuels and their impact on environment.

Gasoline: Chemical composition, combustion characteristics of gasoline, Effect of various engine parameters on the combustion of gasoline; Knocking, Octane number, Effect of sulphur, ash forming additives, oxygenates, olefins, aromatics, benzene content.

Diesel: Chemical composition, combustion characteristics of diesel, Engine parameters affecting the combustion of diesel ; Cetane number, sulphur content, density, volatility, distillation characteristics.
Ethanol and Methanol: Benefits of using ethanol, methanol as fuel, their method of production, properties of ethanol, methanol, methods of using ethanol, methanol in diesel engines: Fumigation, solutions, Spark injection, dual injection, ignition improvers, surface ignition, low heat rejection.

Biodiesel: Definition, advantages of biodiesels, methods of producing biodiesels; blending, cracking, Transesterification, super critical methanol Transesterification, properties of biodiesels, emission characteristics of biodiesels.

Gaseous Fuels: LPG, LNG and CNG Composition, combustion characteristics, dispensing methods, emission studies. Hydrogen, its combustion characteristics, flashback control technique, safety aspects and system development.Biogas, producer gas, their method of preparation, their use as an engine fuel.

Books Recommended

1. Biodiesel, Basics And Beyond New Society Pub 2006
2. McGowan, Thomas Biomass and Alternate Fuel Systems: An Engineering and Economic Guide Wiley-AIChE 2009
3. Processing and Testing of Biodiesel Fuels Serials Publications 2009.

ME-570	Applied Combustion	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To enable the students to understand the fundamentals of combustion and different modes of burning
CO2	To understand the working of various combustion devices and their complicacies involved
CO3	To understand the key features required for developing technologies based on combustion process
CO4	To make students understand the future avenues in combustion technology.

Review of combustion fundamentals. Gas-fired furnace combustion.Oil-fired furnace combustion. Gas turbine spray combustion. Combustion of solids.Industrial applications involving combustion.Burner design, testing and control.Emissions.Combustion safety.

Books Recommended

1. Kenneth Kuan-yunKuo, Principals of Combustion, John Wiley and Sons, NY (2005).
2. Stephen R. Turns, An Introduction to Combustion: Concepts and Applications, 2nd Edition, Mc-Graw Hill, (2005).
3. Norbert Peters, Turbulent Combustion, Cambridge University Press, First Ed. (2000).

ME-571	Combustion Generated Pollution and Control	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the fundamental knowledge of thermodynamics and chemical kinetics of combustion
CO2	Apply the general principles of combustion of fuels
CO3	Explain the formation mechanisms of combustion-generated air pollutants
CO4	Understand and select appropriate methods for air pollution measurement and control
CO5	Determine the air pollutant concentration and dispersion from sources.

Generation and nature of pollutants from various combustion sources, their effects on health and the environment.Emissionindices.Thermo-chemistry of pollutant formation, stoichiometry, chemical thermodynamics, kinetics.Pollutants from I.C. engines, power plants, domestic and other sources.Meteorology and dispersion of pollutants, instruments for pollutant measurement and monitoring.Legislation and emission standards.

Books Recommended

1. Edward f. Obert, Internal Combustion Engine and air pollution, Intent Education publishers.
2. John B.Heywood, Internal Combuston Engine Fundamentals, McGraw Hill Book, 1988.
3. Crouse William, Automotive Emission Control, Gragg Division/McGraw Hill, 1980.
4. Ernst S.Starkman, Combustion Generated air pollution, Plenum Press.
5. George Springer and Donald J.Patterson, Engine Emissions, Pollutant formation and measurement, Plenum press.
6. Obert.E F, IC Engines and air pollution, Intent Education publishers.

ME-572	Cryogenic Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the various thermodynamics cycles used for cryogenics
CO2	To understand the practical applications of cryogenics in space, rocket, biotechnical applications
CO3	To develop understanding in the storage of working fluid used for cryogenics
CO4	To develop skill for the understanding of the type and phase of working fluid used for cryogenics.

Cryogenic Systems, Introduction, Insight on Cryogenics, Properties of Cryogenic fluids, Material properties at Cryogenic Temperatures, Carnot Liquefaction Cycle, F.O.M. and Yield of Liquefaction Cycles. Inversion Curve - Joule Thomson Effect, Liquefaction Cycles, LindeHampson Cycle, Precooled LindeHampson Cycle, Claudes Cycle, Dual Cycle, Helium Refrigerated Hydrogen Liquefaction Systems. Crtical components in Liquefaction Systems, Cryogenic Refrigerators: J.T.Cryocoolers, Stirling Cycle Refrigerators, G.M.Cryocoolers, Pulse Tube Refrigerators, Regenerators used in Cryogenic Refrigerators, Magnetic Refrigerators, Applications: Applications of Cryogenics in Space Programmes, Superconductivity, Cryo Metallurgy, Medical applications, Cryogenic heat transfer: applications, Material Properties at cryogenic temperatures, specific heats and thermal conductivity of solid, liquid and gases, Cryogenic insulations, gas-filled and evacuated powders and fibrous materials, microsphere and multi-layer insulations.

Books Recommended

1. R.B. Scott, *Cryogenic Engineering*, Van Nostrand and Co., 1962
2. Herald Weinstock, *Cryogenic Technology*, 1969
3. Robert W.Vance, *Cryogenic Technology*, Johnwiley& Sons, Inc., New York, London,
4. Klaus D.Timmerhaus and Thomas M.Flynn, *Cryogenic Process Engineering, Plenum Press*, 1989
5. Randall F.Barron, *Cryogenic Systems*, McGraw Hill, 1985.

ME-573	Exergy Analysis of Thermal and Energy System	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To enable the students to understand the exergy method of energy systems
CO2	To develop the knowledge of students in applying the exergy approach to solve the problems of thermal power plants
CO3	Design the thermal and energy systems with exergy approach
CO4	Do the exergetic analysis to find the bottlenecks in the process/component. Identify the drawbacks and recommend the modifications.

Concept of exergy – Available work – Exergy loss, Reversibility and irreversibility – exergy for control region – physical exergy and chemical exergy – closed system analysis – Exergy evaluation of solid, liquid and gaseous fuels – tables and charts.

Thermodynamic Properties: Combined first and second law equation-Maxwell relations - Clapeyron equation – internal energy, enthalpy, entropy, exergy – specific heats as a function of temperature and pressure.
Thermodynamic Equilibrium: Combustion – Combustion reactions - Enthalpy of formation - Entropy of formation - Reference levels for tables - Heat of reaction - Adiabatic flame temperature – General product – Enthalpies – Equilibrium – Chemical equilibrium of ideal gases – Effects of Non-reacting gases– Equilibrium in multiple reactions – The vont Hoff Equation – The chemical potential and phase equilibrium – The Gibbs Phase Rule.
Numerical methods: Use of numerical methods to solve the exergy problems with iterations.
Exergy Applied to Processes: Expansion process - compression process – heat transfer processes – mixing and separation processes – chemical process and combustion – Linde air liquefaction plant – CHP plant – GT-ST combined cycle plant – refrigeration plant – heat pump systems – fuel cell systems.
Thermoeconomic Applications of Exergy: Structural coefficients exergy losses – optimization of component geometry – thermoeconomic optimization of thermal systems – thermoeconomic optimization of heat exchanger in a CHP plant – exergy costing in multi product plant.

Books Recommended

1. Dinçer, Marc A. Rosen, 2007, Exergy: Energy, Environment, and Sustainable Development, Elsevier.
2. Lucien Borel, Daniel Favrat, Thermodynamics and Energy Systems Analysis: From Energy to Exergy (Engineering Sciences-Mechanical Engineering), 2010 EPFL Press.
3. Valero A., C. C., 2009, “Thermoeconomic Analysis,” Encyclopedia of Life Support Systems,Vol. Exergy, Energy System Analysis, and Optimization, Oxford, United Kingdom: EOLSS Publishers.
4. KalyanAnnamalai, Ishwar K. Puri, Milind A. Jog, 2011, Advanced Thermodynamics Engineering, Second Edition (Computational Mechanics and Applied Analysis), CRC Press.
5. Aloui, Fethi, and Ibrahim Dincer, eds. 2018. Exergy for A Better Environment and Improved Sustainability, Volume 1, Series title: Green Energy, Technology, Springer, Cham.

ME-574	Experimental Methods and Analysis	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the importance of doing experiments in investigation of physical systems
CO2	To understand the importance of experimental data and its analysis
CO3	To understand various techniques and their selection for experimental investigations.

Statistics: Distributions, estimators, confidence levels, sample size, test of hypothesis, goodnessof- fit test Chauvenet’s criteria; Regression analysis, co-relations. Uncertainty analysis.Design of experiments.

Instruments: Specifications. Static and dynamic characteristics.Instruments for measuring distance, profile, pressure, temperature, velocity, flow rate, level, speed, force, torque, noise, chemical analyses.Estimation of systematic errors. Signal conditioning, data acquisition and analysis. Transducers, A-D & D-A converters, interfacing with computers and PLCs.

Control theory fundamentals: Steady state and transient response, Stability analysis Routh and Nyquist criteria, Root locus method. Sequence and programmable logic controllers.Hydraulic, pneumatic and electrical systems.

Laboratory: Calibration. Experiments related to heat transfer, fluid mechanics, thermodynamics and gas dynamics. Project on experiment design including drawings, wiring diagrams, selection of instruments and computer interfacing.Use of various controllers and actuators.Data management and presentation.

Books Recommended

1. Dally J E and Rilley W P, "Experimental Stress Analysis", 3rd Edition, McGraw Hill, New Delhi (1991).
2. Dove R C and Adams P H, "Experimental Stress Analysis and Motion Measurement", McGraw Hill, New York (1978).
3. Holister C S, "Experimental Stress Analysis", 5th Edition, Cambridge University Press (1987).
4. Dally J E and Rilley W P, "Introduction to Photomechanics", Prentice Hall Inc, NJ (1981).
5. Mubeen A, "Experimental Stress Analysis", 1st Edition DhanpatRai and Sons, New Delhi (1997).

ME-575	Gas Dynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the concept of different types of shocks and waves: normal and oblique, compression and expansion waves
CO2	To understand the compressible flow behavior with friction and heat transfer
CO3	To understand applications in measurement of subsonic and supersonic flows, wind tunnels, medical, aircraft and rocket propulsion
CO4	To provide introduction hydraulic turbines and pumps.

Recapitulation of fundamentals, introduction to numerical analysis of compressible flow. Oblique shocks, compression and expansion waves, Prandtl Meyer expansion. Interaction of shock waves and shock-boundary layer interaction. Flow with friction and heat transfer. Introduction to 1-D transient and 2-D compressible flow.Method of characteristics. Applications in measurement of subsonic and supersonic flows, wind tunnels, medical, aircraft and rocket propulsion. Introduction to hypersonic, high temperature flows and astro gas dynamics.fans.Surge, stall.Hydraulic turbines and pumps.

Books Recommended

1. Shepherd D G, "An Introduction to Gas Turbine", Von Nastrand, New York (1949).
2. Stodola A, "Steam and Gas Turbines", McGraw Hill Book Company, (1970).
3. Shapiro A M, "Dynamics and Thermodynamics of Compressible Fluids", Ronald's Press, New York (1953).
4. Benson R W, "Advanced Engineering Thermodynamics", Pergamon Press, London (1975).
5. Cohen H, Rogers G F C and Saravanamuttoo H I H, "Gas Turbine Theory", Orient Longman Limited, New Delhi (1996).

ME-576	Gas Turbines and Jet Propulsion	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the applications of turbines and jet propulsion and their energy requirements
CO2	To understand the various thermodynamics cycles used for cryogenics
CO3	To understand the concept of performance and combustion
CO4	Understand the principles of jet propulsion. Types of aircraft engines.

Introduction , Centrifugal fans Blowers and Compressors, Brayton cycle, regeneration and reheating cycle analysis., Axial flow fans and compressors, Elementary theory, degree of reaction, three dimensional flow, simple design methods, blade design, calculation of stage performance, overall performance and compressibility effects. Performance characteristics.
Axial flow turbines: elementary theory, vortex theory, choice of blade profile, pitch and chord estimation of stage performance, he cooled turbine, Combustion system: Form of combustion, important factors affecting combustion chamber design, combustion processes, combustion chamber performance, practical problem., Simple gas turbines: Components, characteristic, pressure losses, methods of improving part load performance, behaviour of gas turbines, Gas turbine rotors and stresses, Jet Propulsion -introduction - Early aircraft engines -Types of aircraft engines - Reciprocating internal combustion engines - Gas turbine engines - Turbo jet engine - Turbo fan engine - Turbo-prop engine. Aircraft propulsion theory: thrust, thrust power, propulsive and overall efficiencies.

Books Recommended

1. Cohen and Rogers, *Gas Turbines Theory*, Wesley Longman, 1996.
2. J.F. Lee, *Theory and design of stream and gas turbine*, McGraw Hill, 1954.
3. V. Ganesan, *Gas Turbine*, Tata McGraw Hill, 3rd edition, 2010.
4. R. Yadav, *Steam & Gas Turbines and Power Plant Engineering*, Central Publishing House, 2004.

ME-577	Measurements in Thermal Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the concepts of errors in measurements, statistical analysis of data, regression analysis, correlation and estimation of uncertainty
CO2	Describe the working principles in the measurement of field and derived quantities
CO3	Analyze sensing requirements for measurement of thermo-physical properties, radiation properties of surfaces, and vibration
CO4	Understand conceptual development of zero, first and second order systems. Interpret International Standards of measurements (ITS-90) and identify internationally accepted measuring standards for measurands.

Basic concepts of measurements, Different types of errors in measurements,Statistics in Measurements, Principle of least square in measurements, Standard deviation, variance, Uncertainty in measurements, Influence coefficients, Linear regression, Least square fit, Goodness of fit, Correlation coefficient, Index of correlation, Error band, Multiple linear regression, Parity plot, Temperature measurements (Thermometry): Fundamental process of measurements, Thermometric thermometer(thermocouples), Thermoelectricity, Seebeck effect, Peltier effect, Thomson effect, Laws of Thermoelectric circuits, Common thermocouple pairs used in practice, Thermocouple junction in series, Measurement of temperature of a moving fluid using a thermo well, Temperature measurement in the solid, Measurement of Transient temperature, Resistance Thermometer, Measurements of temperature in Thermal radiation, Spectroscopic determination of gas temperature. Measurements of Heat Flux, Interferometry, Differential Interferometer, Pressure Measurements: Different pressure measurements, Vacuum measurements, Pirani gauge, Ionization gauge, Dynamic response of a U-tube manometer. Flow and velocity Measurements, Different methods of incompressible and compressible flow measurements, Pitot static tube, Hot wire anemometer, Ultrasonic method, Doppler effect, Vortex Shedding Flow meter, Laser Doppler velocity meter.Viscosity Measurement: Capillary method, Torque method, Saybolt viscometer, Pollution monitoring, Gas chromatography, NDIR analyzer.

Books Recommended

1. J.P.Holman, Experimental Methods for Engineers, McGraw Hill, 2001.
2. S.P.Venkateshan , *Measurements in Thermal Engineering*, Ane Books Pvt.Ltd.,
3. S.M.Yahaya, *Compressible Flow*, New Age International(p) Ltd., 2nd edition, 1998.

ME-578	Microscale Transport Phenomena	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding of the fundamentals of microscale fluid and heattransfer phenomena;
CO2	Understanding of dominant forces and their effects in microscale devices and systems
CO3	Understanding of the differences between the macro-and microscale fluid flows and heat transfer phenomena
CO4	Understanding of various microfluidic applications; and to explore new possible microfluidic applications in the numerous emerging fields.

Introduction: Origin, Definition, Benefits, Challenges, Commercial Activities, Physics of Miniaturization, Scaling Laws. Hydraulic Resistance and Circuit Analysis, Straight Channel of Different Cross-Sections, Channels in Series and Parallel.

Single-Phase Liquid Flow: Micro-Scale Fluid Mechanics: Intermolecular Forces, States of Matter, Continuum Assumption, Governing Equations, Constitutive Relations, Pressure Driven Liquid Micro-flow, Physics of Near-Wall Microscale Liquid Flows, Low *Re* Flows, Entrance Effects. Exact Solutions, Couette Flow, Poiseuille Flow, Stokes Drag on a Sphere, Time Dependent Flows.

Microscale Heat Conduction: Energy Carriers, Time and Length Scales, Scale Effects, Fourier's Law, Scale Effects of Thermal Conductivity.

Microscale Convection: Scaling laws, Temperature jump boundary condition, Convection in parallel plate channel flow and Couette Flow With and Without Viscous Dissipation, Heat Transfer in Micro Poiseuille Flows, Similarity and Dimensionless Parameters, Flow Boiling in Micro Channels, Nucleate and Convective Boiling, Saturated and Sub-Cooled Flow Boiling, Condensation Heat Transfer in Micro Channels, Micro Heat Pipes.

Single-Phase Gas Flow: Boundary Conditions, Wall Slip Effects and Accommodation Coefficients, Flow Analysis of MicroscaleCouette Flows, Pressure Driven Gas Micro-Flows with Wall Slip Effects, Effects of Compressibility, Introductory Concepts on Gas Flows in Transitional and Free Molecular Regimes.

Some Representative Applications of Micro-Scale Flows: Micro-Propulsion and Micro Nozzles, Micro-pumps, Micro-valves, Micro-flow sensors and Accelerometers, Micromixers, Micro-particle separators, Micro-reactors.

Books Recommended

1. P. Tabeling, Introduction to Microfluidics, Oxford University Press, 2005.
2. G. Karniadakis, A. Beskok, N. AluruMicroflows&Nanoflows: Fundamental andSimulation, Springer Publication, 2005.
3. J. Berthier and P. Silberzan, Microfluidics for Biotechnology, Artech House, 2006.
4. H. Bruus, Theoretical Microfluidics, Oxford University Press, 2008.

ME-579	Multi-Phase Flow and Heat Transfer	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand concept of multi phase flow and general governing equations
CO2	Understand physics involved in complex multiphase fluid flows
CO3	Analyse heat transfer and fluid dynamics involved in Pool and boiling
CO4	Evaluate film and dropwise condensation.

Introduction: Review of 1-D conservation equations in single phase flows; Governing equations for homogeneous, separated and drift-flux models.

Flow pattern maps: Horizontal and vertical systems; Simplified treatment of stratified, bubbly, slug and annular flows.

Pool Boiling: Thermodynamics of Pool boiling- onset of nucleation, heat transfer coefficients, critical heat flux, effect of sub-cooling.

Flow boiling: onset of nucleation, heat transfer coefficients, critical heat flux, effect of sub-cooling. Condensation- Film and dropwise condensation.

Books Recommended

1. G.B. Wallis, One dimensional two-phase flow, McGraw Hill, 1969.
2. J.B. Collier and J.R. Thome, Convective boiling and condensation, Oxford Science Publications, 1994.
3. Cebeci,T. and Bradshaw, P., Physical and Computational Aspects of Convective Heat Transfer, Springer-Verlag, 1984.
4. Cebeci,T. and Bradshaw,P., Momentum Transfer in Boundary Layers, McGraw Hill, 1977.
5. Patankar,S.V., Numerical Heat Transfer and Fluid Flow, McGraw Hill, 1980.

ME-580	Optimization Theory	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand basic mathematical concepts of optimization
CO2	Develop modeling skills necessary to describe and formulate optimization problems
CO3	To understand different methods of optimization and be able to suggest a technique for a specific problem
CO4	Develop skills necessary to solve and interpret optimization problems in engineering.

Basic Concepts, optimal problem formulation. Single variable optimization algorithms: bracketing, region elimination, point estimation, and gradient based methods, root finding, Multivariable optimization algorithms: unidirectional search, direct search methods, simplex search and gradient based methods. Constrained optimization algorithms : penalty function method, method of multipliers, sensitivity analysis, direct search for constrained minimization, linearized search techniques, feasible direction method, generalized reduced gradient method, and gradient projection method. Nontraditional optimization algorithms: Genetic algorithms, simulated annealing, and global optimization Computer programming practice for general design applications.

Books Recommended

1. S.S. Rao, *Engineering Optimization: Theory and Practice*,New Age International Publishers, 2006.
2. S.Bradley, A.Hax, T.Magnanti, *Applied mathematical programming*. Addison Wesley, 1977.
3. Rardin L. Ronald, *Optimization in operations research*, Prentice Hall. 1997.

4. Strang and Gilbert, Introduction to applied mathematics, Wellesley-Cambridge press, 1986.
5. K.Deb, *Optimization for engineering design: algorithms and examples.* Prentice Hall of India,New Delhi. 1996.
6. C.Balaji, Essentials of Thermal System Design and Optimization, Ane Books Pvt. Ltd., 2011.

ME-581	**Photovoltaic Cell and its Applications**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the physical principles of the photovoltaic (PV) solar cell and what are its sources of losses
CO2	To know the electrical (current-voltage and power-voltage) characteristics of solar cell, panel or generator and how the environment parameters influence it
CO3	To know the most important characteristics of the elements within a PV system, battery and charge controller, DC/DC converter, DC/AC converter (inverter) and loads
CO4	To understand the role of solar energy in the context of regional and global energy system, its economic, social and environmental implications, and the impact of technology on a local and global context
CO5	To know the main lines of research in the field of photovoltaic technology and solar energy.

Solar Radiation: Introduction, Measurement of Solar Radiation on Earth’s Surface, Sun–Earth Angles, Solar Radiation on a Horizontal Surface, Solar Radiation on an Inclined Surface, Solar Cell Materials and Their Characteristics, Introduction, Doping, Fermi Level, p-n Junction, p-n Junction Characteristics, Photovoltaic Effect, Photovoltaic Material, Basic Parameters of Solar Cells, Effect of Cell Temperature on Cell Efficiency, Current Research on Materials and Devices, Silicon Processing.

PV Array Analysis: Introduction, Photovoltaic (PV) Module and Array, Theory and Construction, Series and Parallel Combinations, Balance of PV Array, Partial Shading of Solar Cell and Module, Maximum Power Point Tracker (MPPT), International Status of PV Power Generation.

Role of Batteries and Their Uses: Introduction, Fundamental Principles, Electro-chemical Action, Physical Construction, Discharge Characteristics, Charging Characteristics, Selection of PV Battery, Batteries Commonly Used for PV, Applications, Battery Installation, Operation and Maintenance, Battery Protection and Regulating Circuits Battery Simulation and Sizing,Battery Lifetime in a PV System, Charging State of PV-powered Storage Batteries, General Terms.

Thermal Modelling of Hybrid Photovoltaic/Thermal (PV/T) Systems: Introduction, PV/T Air Collectors, Hybrid Air Collector, Double-pass PV/T Solar Air Collector, Thermal Modelling of PV/T Air Collector, Covered by Glass-to-Tedlar Type PV Module, Thermal Modelling of PV/T Air Collector, Covered by Glass-to-Glass Type PV Module, Testing of the Solar Air Collector, PV/T Solar Water Heater, PV/T Solar Distillation System, Active PV/T Distillation System, PV/T Solar Dryers,Statistical Analysis

Energy and Exergy Analysis: Energy Analysis, Energy Matrices,Embodied Energy, Embodied Energy of PV Module (Glass-to- Glass) Balance of System (BOS), Analysis of Embodied Energy and EPBT of PV/T Solar Systems, Energy Pay-back Periods of Roof-mounted Photovoltaic Cells, Exergy Analysis, Importance of Exergy, Exergy of a Process, Exergetic Analysis of Flat-plate Collector, Exergetic Analysis of PV/T Systems.

Economic Analysis: Introduction, Cost Analysis, Cash Flow, Cost Comparisons with Equal Duration, Cost Comparisons with Unequal Duration, Analytical Expression for Payout Time, Net Present Value, Benefit-Cost Analysis, Internal Rate of Return, Effect of Depreciation, Cost Comparisons of Solar Dryers with Duration.

Case Studies of PV/T Systems: Introduction, Different types of case study Grid-connected Building Integrated, Photovoltaic System (BIPV), PV-integrated Water-pumping Application, Simulation of an Existing BIPV System for Indian Climatic Conditions etc.

ME-582	Refrigeration Systems and Components Design	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To know about the design of various refrigeration system components
CO2	To learn some different refrigeration systems
CO3	To understand the components of vapor compression systems and other types of cooling systems
CO4	To learn about design of cold storages, mobile refrigeration system and various commercial applications of refrigeration.

Introduction to various components.Thermal design of reciprocating, centrifugal and screw compressors.Capacity control methods.Thermal design of different evaporators–DX, flooded, etc.Thermal design of condensers–water-cooled and air-cooled.Sizing of capillary. Selection of expansion valves and other refrigerant control devices. Components balancing. Testing and charging methods. Design of absorber and generator of vapor absorption systems. Design of cold storages, mobile refrigeration, refrigerators, commercial appliances.

Books Recommended

1. Arora C P, "Refrigeration and Air Conditioning", 19th Edition, Tata McGraw Hill, Delhi, 1985.
2. Pradad M, "Refrigeration and Air Conditioning", 2nd Edition, New Age International Private Limited, Delhi (2002).
3. Dossat, R J, "Principles of Refrigeration", 4th Edition, Pearson Education (Singapore), India, 2002.
4. Mcquiston F G, Parker J D and Spilter J D, "Heating, Ventilating, and Air Conditioning", 5th Edition, John Wiley and Sons Inc, New York, 2001.
5. Jordan and Prister, "Refrigeration and Air Conditioning", Prentice Hall of India, 1998.

ME-583	Renewable Energy	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To explain the basic principles of various renewable energy conversion processes and devices used therein
CO2	To identify various parameters that influences the performance of renewable energy devices/processes
CO3	To undertake the field projects in the area of solar thermal, solar PV, wind, biomass, ocean energy, geothermal etc.
CO4	To identify suitable renewable source and technology for a given requirement
	To develop the integrated renewable energy technology for decentralized power sector.

Need of sources of renewable energy, Introduction to different sources of renewable energy, e.g., Solar Energy, Wind Energy, Bio-mass, Geothermal Energy, Ocean energy, Solar Energy and Applications , Basic concepts, , Flat plate and concentrating collectors, applications such as Air Heater, water heaters, thermal energy storages, photo: voltaic cell, Wind Energy, Sources and potentials, horizontal and vertical axis windmills, performance characteristics, Augmentation of wind power, Betz criteria, Bio-Mass: Principles of Bio-mass conversion, Anaerobic/Aerobic digestion, types of Bio-gas digesters, Combustion characteristics of bio-gas and its different utilizations, Geothermal Energy: Resources, methods of harnessing energy, Ocean Energy: Principles utilization, thermodynamic cycles, tidal and wave energy, potential and conversion technique.

Books Recommended

1. John A. Duffie and William A. Beckman, *Solar Engineering forThermal Process*, Wiley and Sons, 2013.
2. Tiwari and Ghoshal, *Renewable Energy Sources*, Narosa Publication, 2007.
3. K.Mittal, *Non-conventional energy systems*, Wheeler Publ House, 2003.
4. S.P.Sukhatme, *Solar Energy- Principles of Thermal Collection and Storage*, TMH, 2005.
5. H.P. Garg, *Solar Energy*, TMH, 1997.
6. D.P.Kothari and K.C.Singhal, *Renewable Energy Sources and emerging technologies*, PHI Learning private Ltd., 2nd edition, 2012.

ME-584	Solar Passive Design and Sustainable buildings	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the basic principles and fundamentals of mechanical engineering in the building integrated passive design
CO2	To understand the interrelation of engineering and building science for sustainable development in built environment
CO3	To provide a bird eye view of Indian building compliance codes and energy efficiency measures for sustainable buildings and building integrated systems.

Introduction: Heating and cooling load of buildings: elements of heating and cooling load, load reduction approaches.

Passive heating and cooling in buildings:Direct and indirect solar passive heating systems; solarium, trombe wall, trans-wall, thermal mass, courtyard effect, wind tower design, earth air tunnel system, evaporative cooling, radiative cooling.

Green and Sustainable buildings: Concept of green buildings, features of green building rating systems in India, indoor environment issues for green buildings, Green home rating system, Concept of Net zero energy building.
Building Energy Codes: Energy Conservation Building Code: requirements of code, applicability, compliance options: prescriptive, trade-off, whole building performance methods.

Books Recommended

1. Passive and low energy cooling of building by Baruch Givoni (John Willey & Sons).
2. Advances in Passive Cooling by MatheousSantamouris (Earthscan, London).
3. Passive Building Design: A handbook of natural climate control (N K Bansal, G Hauser, GMinke).
4. Energy Conservation Building Code (ECBC, 2016), Bureau of Energy Efficiency, India.

ME-585	Thermal Behaviour of Advanced Materials	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand various strengthening mechanisms of materials
CO2	Learn about thermal behaviour of advanced materials like Ceramics, Composites, Shape memory alloys, Metglasses, and Nanostructured Materials
CO3	Understand accounting for creep in development of technologically important materials such as long-fibre composites and discontinuously reinforced composites

CO4	Learn about heat treatment mechanisms, Conductivity and Internal thermal resistance of composites.

Basic Information about the Material, Elastic behavior of materials, concept of engineering and true stress and true strain, tensile property, yield point phenomenon & elastic modulus. Heat Treatment Processes, Strengthening Mechanisms of Materials, Basics of Thermal, Optical, Electrical and Magnetic Properties of Materials, Concepts of Creep, Fatigue, Fracture and Corrosion, Introduction to Ceramics, Composites, Shape Memory Alloys, Metglasses, and Nanostructured Materials, Thermal Behaviour of Composites,Thermal expansion and thermal stresses: Thermal stresses and strains, Thermal expansivities, Thermal cycling of unidirectional composites, Thermal cycling of laminates, Creep: Basics of matrix and fibrebehaviour, Axial creep of long-fibre composites, Transverse creep and discontinuously reinforced composites,Thermal Conduction: Heat treatment mechanisms, Conductivity of composites, Internal thermal resistance.

Books Recommended

1. T. E. Reed-Hill & R Abbaschian, *Physical Metallurgy Principles*, Thomson.
2. L.H. Van Vlack, *Elements of Materials science & Engineering*, Addison Wesley Pub. Company,
3. Hull and Clyne, *An Introduction to Composite Materials*, Cambridge University Press,
4. Diwan and Bhradwaj, *Nano Composites*, Pentagon Press, New Delhi.
5. William D CallisterJr, *Materials Science and Engineering*, John Wiley & Sons, Inc.
6. G.E. Dieter, *Mechanical Metallurgy*, McGraw-Hill, London.
7. V.Raghvan, *Materials Science and Engineering*, Prentice Hall of India.

ME-586	Turbomachinery	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand various devices used for power production and transmission
CO2	To understand the working principles and analysis of various turbo-machines
CO3	To understand various operation difficulties involved in turbo-machines
CO4	To understand various techniques to improve the performance of various turbo-machines.

Introduction, Classification of turbo machinery.Application of Time Temperature diagram – theorem in turbo machinery.Incompressible fluid flow in turbomachines – Effects of Reynolds Number and Mach number. Energy transfer between a fluid and a rotor - Euler turbine equation – components of energy transfer – impulse and Reaction – Efficiencies, Radial flow pumps and compressors – head capacity relationship – Axial flow pumps and compressors – Degree of reaction dimensionless parameters – Efficiency and utilization factor in Turbo Machinery, Thermodynamics of Turbo machine processes – Compression and expansion efficiencies – Stage efficiency – Infinitesimal stage and finite stage efficiencies, Flow of fluids in Turbo machines – flow and pressure distribution over an airfoil section – Effect of compressibility cavitations – Blade terminology- Cascades of blades – fluid deviation – Energy transfer of blades – Degree of reaction and blade spacing – Radial pressure gradient – Free vortex flow – losses in turbo machines, Centrifugal pumps and compressors – Inlet section – Cavitation – flow in the impeller channel – flow in the discharge casing pump and compressor characteristic, Radial flow turbines – inward flow turbines for compressible fluids – inward flow hydraulic – velocity and flow coefficients – gas turbine blading – Kaplan turbine – pelton wheels.

Books Recommended

1. Lee, *Theory and Design of Steam and Gas Turbine*, McGraw Hill, 1954
2. S.M.Yahya, *Turbines, Compressions & Fans*, Tata McGraw Hill. 1983.
3. J.Lal, Hydraulic Machines, Metropolitan Books Co. Ltd, N.Delhi, 1956.

ME-587	Waste Heat Utilization and Polygeneration	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply the knowledge of power generation configurations for power and process heating to suit the waste heat recovery
CO2	To estimate performance of integrated energy system with suitable applications. To develop the layouts for the desalination and cooling integration
CO3	To apply the knowledge of energy storage for poly-generation. To design the heat exchangers for poly-generation with waste heat recovery
CO4	To justify the poly-generation plants with the thermos-economic evaluation.

Power generation: Review of Thermodynamics, Indian potentials and scenario for power generation, cogeneration and polygeneration. Methods of improving the current technologies.Power cycles and their limitations, organic Rankine cycle, areas of major losses.Micro turbine systems, decentralized power generation, direct conversion technologies – Thermoelectric generators, Thermoionic conversion, Thermo-PV, MHD. Combined cycle, combined gas turbine-steam turbine power plant, heat recovery steam generators.Heat recovery vapor generators.Thermodynamic cycles for low temperature application.
Cogeneration: Topping cycle cogeneration. Industrial Examples: Process heating in sugar plants, paper and other industries. Bottoming cycle: Waste Heat Boilers, Metal industries, cement plants and potential in power plants. Case studies on cogeneration.
Desalination and Cooling: Desalination- basics. Types of desalination systems. Vapor absorption refrigeration system – concept - working – types. Case studies.
Trigeneration: Multi product polygeneration- multi fuel polygeneration - Case studies on trigeneration and polygeneation systems – Performance calculations. Efficiency of polygeneration compared to stand-alone production.
Waste heat recovery: A case study for heat recovery - potential in India. Special heat exchangers for waste heat recovery, Synthesis of heat exchanger network. Pinch technology, Selection of pinch temperature, stream splitting, process retrofit, insulation, fins, effective use of heat pumps and heat engines, heat pipes.
Design of heat recovery systems: Effectiveness, Types of heat exchangers – LMTD- effectiveness-NTU methods. Recuperative, Regenerative, run-around coils.
Energy Storage: Pumped hydro, Compressed air, Flywheel, Superconducting magnetic storage. Smart buffers (batteries, hot and cold thermal energy storage, pure water reservoirs, etc).
Techno-economics: Investment cost – economic concepts – measures of economic performance – procedure for economic analysis – examples – procedure for optimized system selection and design – load curves – sensitivity analysis – regulatory and financial frame work for cogeneration and waste heat recovery systems,Thermoeconomic optimization of polygeneration systems.

Books Recommended

1. Eastop, T.D. & Croft D.R, "Energy efficiency for engineers and Technologists", 2nd edition, Longman Harlow, 1990.
2. EDUCOGEN – The European Educational tool for cogeneration, Second Edition, 2001.
3. Osborn, peter D, "Handbook of energy data and calculations including directory of products and services", Butterworths, 1980.
4. Charles H.Butler, Cogeneration, McGraw Hill Book Co., 1984.
5. Horlock JH, Cogeneration - Heat and Power, Thermodynamics and Economics, Oxford, 1987.
6. Institute of Fuel, London, Waste Heat Recovery, Chapman & Hall Publishers,London, 1963.
7. Seagate Subrata, Lee SS EDS, Waste Heat Utilization and Management, Hemisphere, Washington, 1983.
8. Srinivas, T. Shankar Ganesh N and Shankar R., 2019, Flexible Kalina Cycle Systems, Taylor and Francis Publishers, CRC press, ISBN: 9781771887137.

CURRICULUM

July 2022 admission onwards

APPROVED BY

BOARD OF STUDIES (BOS)
MEETING, July 19, 2022

M Tech in Design Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

Dr B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY,

JALANDHAR

Phone: 0181-2690301, 02 (Ext. 2101, 2104), Fax: 0181-2690932
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Annexure-F

DR B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY

JALANDHAR

Teaching Scheme and Syllabus
of
Regular M Tech in Design Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

SCHEME OF INSTRUCTION AND DETAILED SYLLABI

MASTER OF TECHNOLOGY IN DESIGN ENGINEERING

EFFECTIVE FROM JULY, 2022 ONWARDS

Course Scheme for M Tech in Design Engineering

FIRST SEMESTER				
S. No.	Course No.	Subjects	L-T-P	Credit
1.	MA-553	Computational Methods in Engineering	3-0-0	3
2.	ME-501	Continuum Mechanics	3-0-0	3
3.	ME-503	Materials in Mechanical Design	3-0-0	3
4.	ME-505	Finite Element Methods	3-0-0	3
5.	ME-XXX	Programme Elective-I	3-0-0	3
6.	ME-XXX	Programme Elective-II	3-0-0	3
7.	ME-511	Material Selection Laboratory	0-0-3	2
8.	ME-513	Materials Fabrication and Development Laboratory	0-0-3	2
		Total	**18-0-6**	**22**

SECOND SEMESTER				
S. No.	Course No.	Subjects	L-T-P	Credit
1.	ME-502	Advanced Machine Design	3-0-0	3
2.	ME-504	System Dynamics and Control	3-0-0	3
3.	ME-506	Mechanical Vibrations	3-0-0	3
4.	ME-508	Design and Optimizations	3-0-0	3
5.	ME-XXX	Programme Elective-III	3-0-0	3
6.	ME-XXX	Programme Elective-IV	3-0-0	3
7.	ME-512	Design of Mechanical System Laboratory	0-0-3	2
8.	ME-514	Advanced Mechanical Vibration Laboratory	0-0-3	2
		Total	**18-0-6**	**22**

THIRD SEMESTER				
S. No.	Course No.	Subject	L-T-P	Credit
1.	ME-600	Project Work for M Tech Dissertation, Part-I	0-0-12	6
2.	ME-601	Independent Study	0-0-6	3
		Total	**0-0-18**	**9**

FORTH SEMESTER				
S. No.	Course No.	Subject	L-T-P	Credit
1.	ME-600	Project Work for M Tech Dissertation, Part-II	0-0-24	12
		Total	**0-0-24**	**12**

Summary				
Semester	**I**	**II**	**III**	**IV**
Semester-wise total credit	**22**	**22**	**9**	**12**
Total credits	**65**			

Credit Distribution for M Tech in Design Engineering					
Category	**Sem - I**	**Sem - II**	**Sem - III**	**Sem - IV**	**Total No. of Credits to be earned**
Core Courses	**9**	**9**	**-**	**-**	**18**
Electives	**9**	**9**	**-**	**-**	**18**
Lab Courses	**4**	**4**	**-**	**-**	**8**
Seminar	**-**	**-**	**3**	**-**	**3**
Dissertation	**-**	**-**	**6**	**12**	**18**
Total	**22**	**22**	**9**	**12**	**65**

Programme Electives				
S. No.	**Course code**	**Subjects**	**L-T-P**	**Credit**
1.	ME-515	Advanced Material Science	3-0-0	**3**
2.	ME-516	Advanced Solid Mechanics	3-0-0	**3**
3.	ME-517	Automotive Design	3-0-0	**3**
4.	ME-518	Basic Biomechanics	3-0-0	**3**
5.	ME-519	Computer Aided Design	3-0-0	**3**
6.	ME-520	Continuum Damage Mechanics	3-0-0	**3**
7.	ME-521	Control Theory and Applications	3-0-0	**3**
8.	ME-522	Design of Fluid Film Bearings	3-0-0	**3**
9.	ME-523	Fracture Mechanics	3-0-0	**3**
10.	ME-524	Heat Treatment and Surface Hardening	3-0-0	**3**
11.	ME-525	Machine Tool Design	3-0-0	**3**
12.	ME-526	Material Characterization and Properties	3-0-0	**3**
13.	ME-527	Materials and Environment	3-0-0	**3**
14.	ME-528	Materials and Sustainable Development	3-0-0	**3**
15.	ME-529	Mechanics of Composite Materials	3-0-0	**3**
16.	ME-530	Methods of Analytical Dynamics	3-0-0	**3**
17.	ME-531	Modal Analysis of Mechanical Systems	3-0-0	**3**
18.	ME-532	Modern Control Engineering	3-0-0	**3**
19.	ME-533	Nonlinear Finite Element Methods	3-0-0	**3**
20.	ME-534	Nonlinear systems	3-0-0	**3**
21.	ME-535	Robotics: Mechanics and Control	3-0-0	**3**
22.	ME-536	Soft Computing Techniques	3-0-0	**3**
23.	ME-537	Theory of Elasticity	3-0-0	**3**
24.	ME-538	Theory of Plasticity	3-0-0	**3**
25.	ME-539	Theory of Plates and Shells	3-0-0	**3**
26.	ME-540	Tribology	3-0-0	**3**
27.	ME-541	Vibration Control	3-0-0	**3**
28.	ME-542	Vibro-Acoustics	3-0-0	**3**
29.	ME-543	Viscoelasticity	3-0-0	**3**
30.	ME-544	Wave Propagation in Solids	3-0-0	**3**
31.	ME-545	Welding and Allied Processes	3-0-0	**3**

First Semester

MA-553	Computational Methods in Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the stepwise procedure to completely solve a fluid dynamics problem using computational methods
CO2	Ability to solve ODE problems using power series solutions
CO3	Ability to solve PDE using various analytical methods
CO4	Development of a clear understanding on Tensors, their operation and applications.

In relation to mechanical engineering applications, such as, heat transfer, fluid mechanics, vibrations, dynamics and others, the following topics will be covered:

Partial differential equations: Characteristics and classification of 2nd order PDEs. separation of variables special functions, Eigen function expansions, Fourier integrals and transforms, Laplace transforms, methods of characteristics, self-similarity.

Linear algebra: Matrix theory, solution of linear system of algebraic and differential equations; round-off errors, pivoting and ill-conditioned matrices. Eigen values and eigen vectors. Unitary, hermitian and normal matrices.

Numerical Methods: Lagrange interpolation, splines, integration – trapezoid, Romberg, Gauss, adaptive quadrature. Explicity and implicity methods, multi-step methods, Runge-Kutta and predictor-corrector methods, boundary value problems, eigen value problems, systems of differential equations, stiffness. Accuracy, stability and convergence. Alternating direction implicity methods. Non-linear equations.

Books Recommended

1. Ames W F, "Numerical Methods for Partial Differential Equations", 3rd Edition, Academic Press, New York (1992).
2. Dahlquist G and Björck A, "Numerical Methods", Prentice-Hall, NJ (1974).
3. Jain M K, Iyengar S R K. and Jain R K, "Numerical Methods for Scientific and Engineering Computations", 4th Edition New Age International (P) Limited, Publishers, New Delhi (2003).
4. Shampine L F, "Numerical Solution of Ordinary Differential Equations", Chapman and Hall, New York (1994).
5. Kreyszig, E., "Advanced Engineering Mathematics", 8th Ed, John Wiley, Singapore, 2002.

ME-501	Continuum Mechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to use tensor algebra and calculus for calculations and derivations in general (curvilinear) coordinates
CO2	To understand general stresses and deformations in continuous materials
CO3	Be able to formulate and solve problems in linear and nonlinear elasticity and compressible and incompressible fluid mechanics using the general theory
CO4	Be able to convert the physical description of a problem in continuum mechanics into the appropriate governing equations and boundary conditions and, conversely, provide a physical interpretation for the solutions.

Introduction to Continuum Mechanics

Mathematical Preliminaries: Vector and tensor calculus, Tensor analysis, derivatives of functions with respect to tensors Fields, div, grad, curl, Divergence theorem, transport theorem.

Kinematics: Configurations of a body, displacement, velocity, motion, Deformation gradient, rotation, stretch, strain, strain rate, spin tensor, Assumption of small deformation and small strain.

Balance laws: Balances of mass, linear momentum and angular momentum, Contact forces and the concept of stress, Balance of energy and Clausius-Duhem inequality.

Constitutive relation: Frame indifference, Material symmetry, Kinematic constraints (incompressibility, etc.), Thermodynamical restrictions.

Viscous fluid: constitutive relations, non-Newtonian fluid, boundary value problem**.**

Finite elasticity: Hyperelasticity, isotropy, simple constitutive relations, boundary value problem

Books Recommended

1. Continuum Mechanics, A. J. M. Spencer
2. Continuum Mechanics, P. Chadwick
3. An Introduction to Continuum Mechanics, M. E. Gurtin
4. Introduction to the Mechanics of a Continuous Medium, L. E. Malvern
5. Continuum Mechanics, C. S. Jog

ME-503	Materials in Mechanical Design	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the importance of materials selection in the Mechanical Design process and use Material property charts, Material Indices for selecting materials for various types of mechanical systems
CO2	Understand the importance of shape and various shape efficiency factors in the design process
CO3	Solve problems involving multiple objectives and constraints
CO4	Designing Hybrid materials and to undertake analysis of Eco properties of materials.

Materials in design, evolution of engineering materials, Design tools and materials data, Function, material, shape and process. Review of properties of Engineering materials and nomenclature of materials.

Material Selection: Introduction, displaying material properties, material property charts Basics concerning material selection, selection strategy, property limits and material indices, selection procedure and structural index. Material selection –case studies

Selection of Materials and Shape: Shape factor, efficiency of standard sections, materials for shape factors, material indices, microscopic or micro-structural shape factor and co-selecting material and shape. Shape case studies.

Multiple constraints and compound objectives selection by successive application of property limits and indices, methods of weight factors, methods using fuzz logic, systematic methods for multiple constraints, compared objectives, exchange constrains and value functions. Case studies.

Process & Process Selection: Processes and their influence attributes, systematic process selection, screening process selection diagrams, Ranking – process cost, supporting information. Case studies related to processing design.

Designing Hybrid Materials: Introduction, Holes in Material Property Space, Types of Hybrids, Composites, Sandwich Structures, Cellular Structures: Foams & Lattices, Segmented Structures, Case Studies

Materials & Environment: Introduction, Material Life Cycle, Materials and energy consuming systems, Eco Attributes of Materials, Eco Selection of Materials, Eco Audits, Case Studies

Books Recommended

1. Ashby M, "Materials Selection in Mechanical Design", Third Edition, Elsevier, Indian Edition, (2005)
2. Ashby M and Johnson K, "Materials & Design, 2nd Edition- The Art & Science of Material Selection in Product Design", Butterworth-Heinemann (2009)
3. Farag M M, "Materials & Process selection for Engineering Design", 2nd Edition, CRC Press (2007)
4. Popov E P, "Engineering Mechanics of Solids", SI Version 2nd Edition, Prentice Hall of India, New Delhi (2003).

ME-505	Finite Element Methods	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Review the mathematical knowledge studied in previous semester
CO2	To understand the advantage of discretization of the object
CO3	To develop familiarities with FEM software
CO4	To develop program for solving the problems.

Fundamentals of the Finite Element Method, discretization of the domain, one-two and three dimensional elements and interpolation functions, local and global coordinates, properties of interpolation functions, compatibility and completeness requirements, Assembly and boundary conditions; Formulation for FEM solutions. Application to solid mechanics, vibrations, plates and shell problems.

Books Recommended

1. Desai and Abel, *"Introduction to Finite Element Method"*, East West, CBS Delhi (1987).
2. Zienkiewicz O C, *"Finite Element Method"*, McGraw Hill (1989).
3. Krishnamurthy C J, *"Finite Element Method – Analysis Theory and Programming"*, Tata McGraw Hill (1994).
4. Bathe k J, *"Finite Element Procedures"*, Prentice Hall of India Private Limited, New Delhi, (1996).
5. Belegundu Ashok D and Chandrupatla T, *"Introduction to Finite Element Method"*, PHI Private Limited, New Delhi (2003).
6. J. N. Reddy,"An introduction to FEM".

ME-511	Material Selection Laboratory	(0 0 3 2)

Course Outcomes: At the end of the course the student will be able to:

CO1	Use CES Edupack for browsing materials, processes, shapes and sections
CO2	Use CES Edupack for plotting material property charts and use the same for selection problems
CO3	Use CES Edupack for Hybrid materials design
CO4	Use CES Edupack for exploring ECO Design of products.

Material Selection Laboratory course is based upon the use of CES Edupack Software, a material selection package developed by GRANTS Design, Cambridge.

List of Experiment

1. Introduction to CES Edupack- Materials, Families of materials, Materials, Process, Shape Data in CES Edupack.
2. Material Property Charts- Plotting different property charts using CES Edupack
3. Selection of Materials – Selecting Materials using Selection Charts, Material Indices
4. Exploring the Materials, Processes data bases
5. Case Studies on Selecting Materials, Shape
6. Hybrid Materials Design in CES Edupack
7. ECO Data Exploration in CES Edupack.
8. Case Studies using CES Edupack

ME-513	**Material Fabrication and Development Laboratory**	**(0 0 3 2)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Fabrication of components using molding processes
CO2	Fabrication of reinforced composites
CO3	Dynamic testing of composites using Dynamic Mechanical Analyzer (DMA)
CO4	Static testing of composites using advanced UTM.

List of Experiment

1. Fabrication of fiber reinforced polymer composite using compression molding
2. Fabrication of carbon nanotube reinforced metal matrix composite using stir casting
3. Fabrication of any component using vacuum bag molding process.
4. Fabrication of any component using resin transfer molding process.
5. Testing of dynamic properties of polymer matrix composites on Dynamic Mechanical Analyzer (DMA)
6. Testing of mechanical properties of metal matrix composites using Advanced UTM.
7. Demonstration of Ultra-sonication process
8. High strain rate testing of polymer based composites using Advanced UTM

Second Semester

ME-502	**Advanced Machine Design**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the principles involved in evaluating the shape and dimensions of a component
CO2	Be able to design machine components which are subjected to static/dynamic loads
CO3	To learn to use standard practices and standard data
CO4	To learn to use catalogues and standard machine components.

Introduction to Advanced Machine Design, Materials and processes for machine elements, Review of static strength failure analysis and theories of failure, Fracture and fatigue, High cycle and low cycle fatigue, Design of Machine element against fatigue. Stress-Based Fatigue Analysis, Strain-Based Fatigue Analysis, Fracture Mechanics and Fatigue Crack Propagation, Fatigue Analysis in the

Frequency Domain and Design Problems on fatigue design of shafts and gears, rolling contactbearings (surface fatigue design failure). Stiffness based design. Design to prevent buckling and instability. Introduction to MATLAB Programming for Design.

Books Recommended

1. Norton L R, "Machine Design an Integrated Approach", I[st] Indian Reprint, Pearson Education Asia (2001).
2. Sharma P C and Aggrawal D K, "A text book on Machine Design", 9[th] Edition, S K Kataria and sons (2000).
3. Shigley J E and Mischke C R, "Mechanical Engineering Design" Tata Mcgraw Hill, New Delhi, (2003).
4. Richard W Hertzberg, "Deformation and fracture mechanics of engineering materials", John Wiley and sons, Inc Newyork, (1996).
5. Burr H and John B Cheatham, "Mechanical Analysis and Design", PHI Private Limited, New Delhi (2001).

ME-504	**System Dynamics and Control**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the concept of physical systems in multi-energy domains and modeling their dynamics through the unified approach of Bond graph
CO2	Understanding the concept of causality and its implications for deriving system equations from bond graph models
CO3	Understanding and applying principles of classical and modern control theory to the control of multi-energy physical systems
CO4	Ability to simulate models of multi-energy physical systems and analyse their response through case studies.

Introduction to Physical System Dynamics Modeling of Physical System Dynamics: A Unified Approach: Physical systems, Introduction to Bond graphs, Ports, Bonds and Power; Elements of Bond graphs, 1-port elements – resistor R, Stiffness C, and Inertia I, Source of Effort Se and Flow Sf; 2-port elements – Transformer TF and Gyrator GY, with modulation, Junction elements 1 and 0; Causality: Causality for basic 1-port and multi-ports. Derivation of System equations from Bond graphs in first order state space form.

Bond graph modeling of multi-energy systems: Mechanical Systems, Translation and rotation(about a fixed axis), Electrical Systems, Electromechanical Systems, Fluid systems, Transducer models – cylinder, rack and pinion, electromechanical transducers - motors, pumps – positive displacement and centrifugal pump, gear trains, etc.

Analysis of linear systems: Free and forced response for first and second order systems, Undamped and damped oscillator, Derivation of Signal flow graphs from Bond graphs, Derivation of Transfer functions, Bode plots

State variable analysis: State transition matrix, Characteristic equation, Eigen values and Eigen vectors, Their impact on system response, Similarity transformations and their properties, Controllability and Observability, Canonical forms: Controllable, Observable, Diagonal

Stability Criteria: Routh-Hurwitz criterion, Liapunov stability criteria.

Controllers: Pole-placement method, Proportional Integral and Derivative feedback

Simulation and case studies: Computer simulation of Dynamic Systems using Bond graphs

Books Recommended

1. Karnopp, Margolis, Rosenberg, System Dynamics: Modeling and Simulation of Mechatronic Systems, Fourth Edition, Wiley (Higher education), 2005.
2. Karnopp, Margolis & Rosenberg, System Dynamics: A Unified Approach, Wiley, 1990.
3. Amalendu Mukherjee & R. Karmakar, Modeling & Simulation of Engineering Systems through Bond Graphs, Narosa, 2000.
4. Amalendu Mukherjee, Ranjit Karmakar and Arun Kumar Samantaray, Bond Graph in Modeling, Simulation and Fault Identification, I. K. International Publishing House Pvt. Ltd, 2006.
5. ErониniUmez-Eronini, System Dynamics & Control, Brooks/ Cole Publishing Company, 1999. 6. B. C. Kuo, Feedback Control Systems, Prentice Hall.
6. K. Ogata, Modern Control Engineering, Prentice Hall.
7. Bernard Friedland, Control Systems Design, McGraw-Hill.

ME-506	Mechanical Vibrations	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Describe the various fundamentals of vibrations and to represent time domain motion in to frequency domain equation (Fourier series)
CO2	Compute the natural frequencies of vibration of various undamped single degree freedom systems
CO3	Analyze the damped motion without external force for under damped, over damped and critically damped motion
CO4	Analyze harmonic steady state forced vibration systems and related applications
CO5	Explain the different vibration measuring instruments and machine condition monitoring
CO6	Determine the natural frequencies and mode shapes of different two degree and multi degree freedom systems.

Introduction: Brief History of Vibration, importance of study of Vibration, fundamentals of vibration,
classification of vibration. Modeling for vibration - Discrete and continuous vibratory systems.

Single Degree Freedom System: Free vibrations of translational system, torsional system, stability conditions; free vibration with viscous damping, Coulomb damping and Hysteretic damping.

Forced Vibration: Types of excitation, Response of undamped and damped system under – harmonic force, excitation of base, rotating unbalance. Forced response of system with Coulomb and hysteretic damping.

Two Degree Freedom System: Basic concepts, two-degree freedom, discrete model for vibratory systems – examples, Equations of motion, Analysis of undamped vibratory systems, coordinate coupling and principal coordinates, semi-definite system vibration. Forced vibration – frequency response curve and mode shape, stability analysis.

Multidegree Freedom System: Basic concept, modeling, Derivation of equation of motion using – Newton's Second Law, Influence coefficient, Flexibility matrix approach and Lagrange's equation. Eigen value problem and solution.

Natural Frequencies and Mode shapes: Various method for the prediction of natural frequencies and mode shapes – Dunkerley's formula, Raleigh's method, Holzer's method, Matrix Iteration method.

Continuous System: Analysis of transverse vibration of string, longitudinal vibration of bar, Torsional vibration of shaft, and Lateral vibration of beams.

Vibration Control: Need of vibration control – an introduction. Vibration isolation – Force transmitted to the foundation, methods of vibration isolation. Vibration absorbers – basic concept, classification, analysis of undamped and damped vibration absorbers.
Vibration Measurement: Response of vibratory system, vibration measurement scheme, transducers, vibration pickups – seismic instrument, accelerometer. Frequency measurement - Fullartontachometer, Frahm tachometer and stroboscope.

Books Recommended

1. Rao S S, "Mechanical Vibrations", Pearson Education, Delhi (2004).
2. Roger A A, "Fundamentals of Vibrations", Amerind Publisher Company Private Limited, New Delhi (1999).
3. Srinivas P, "Mechanical Vibration Analysis", Tata McGraw Hill Company Limited, New Delhi (1990).
4. Mallik A K, "Principles of Vibrations Control", Affiliated East West Press Private Limited, New Delhi (2000).
5. Daniel J Inman, "Engineering Vibration", Prentice Hall, New Jersey (2001).

ME-508	**Design and Optimizations**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Student will understand how to formulate an engineering optimization problem and thereafter select appropriate tools needed to solve the problem
CO2	Propagating this uncertainty via various computational methods to predict the output quantity of interest
CO3	Ability to write efficient computer programs related to probabilistic methods
CO4	Be able to analytically obtain the necessary conditions for optimizing a bar of variable cross-section profile for different objective functions and constraints.

Introduction: Introduction to design and specifically system design, Morphology of design with a flow chart. Very brief discussion on market analysis, profit, time value of money, an example of discounted cash flow technique. Concept of workable design, practical example on workable system and optimal design.

System Simulation: Classification. Successive substitution method - examples. Newton Raphson method - one unknown - examples. Newton Raphson method - multiple unknowns - examples. Gauss Seidel method - examples. Rudiments of finite difference method for partial differential equations, with an example.

Regression and Curve Fitting: Need for regression in simulation and optimization. Concept of best fit and exact fit. Exact fit - Lagrange interpolation, Newton's divided difference - examples. Least square regression - theory, examples from linear regression with one and more unknowns - examples. Power law forms - examples. Gauss Newton method for non-linear least squares regression - examples.

Optimization: Introduction, Formulation of optimization problems – examples, Calculus techniques – Lagrange multiplier method – proof, examples, Search methods – Concept of interval of uncertainty, reduction ratio, reduction ratios of simple search techniques like exhaustive search, dichotomous search, Fibonacci search and Golden section search – numerical examples, Method of steepest ascent/ steepest descent, conjugate gradient method – examples. Geometric programming – examples, Dynamic programming – examples, Linear programming – two variable problem –graphical solution. New generation optimization techniques – Genetic algorithm and simulated annealing - examples. Introduction to Bayesian framework for optimization- examples.

Books Recommended

1. Introduction to optimum design, J.S.Arora, McGraw Hill, 1989.
2. Optimization for engineering design - algorithms and examples, K.Deb, Prentice Hall, 1995.
3. Engineering Optimization: Theory and Practice, S. S. Rao, New age publishers, 2013.

ME-512	Design of Mechanical System Laboratory	(0 0 3 2)

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to apply design knowledge for Design of gear box for Lathe machine
CO2	Be able to use FEM software for analysing beam problems
CO3	Be able to model for micromechanical damping for composite materials.

List of Experiment

1. Design of Gear box for Lathe machine
2. Design a Mechanical shaker
3. Nonlinear analysis of beam using FEM
4. Design a overhead traveling crane for dynamic response
5. Modeling for micromechanical damping for composite materials

ME-514	Advanced Mechanical Vibrations Laboratory	(0 0 3 2)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the working principle of different vibration equipments
CO2	Analysis of damping of beams using model analysis software
CO3	Analysis of damping of Fibre Reinforced Composite lamina and plates
CO4	Analysis of multi degree freedom system.

List of Experiment

1. Study of vibration equipments: Accelerometer, vibration analyzer, Oscilloscope, Hammers
2. Measurement of deflection of cantilever beam using accelerometer
3. Measurement of damping of Al beam
4. Measurement of damping of cast iron using model analysis software
5. Measurement of damping of Fiber reinforced Composite lamina
6. Measurement of damping of Fiber reinforced composite plates
7. Experimental evaluation of multi degree freedom system

Programme Electives

ME-515	Advanced Materials Science	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of mathematics, science & engineering
CO2	To apply and integrate knowledge of material properties to solve material selection problems
CO3	Ability to learn the basics of nanotechnology and apply the concepts for fabrication of advanced materials.

Introduction – Use and Study of Materials, Properties of Materials, Thermal Expansion, Electrical Conductivity, Free Electron Gas and The Ideal Gas, The Drude Model, Large Systems, Statistical Mechanics and The Maxwell–Boltzmann Statistics.

A Brief History of Quantum Mechanics: Its Use in the Drude–Sommerfeld Model, Fermi–Dirac Statistics, Anisotropy, Periodic Potential, Confinement and Quantization, Density of States, Fermi Energy and The Electronic Contribution to Specific Heat at Constant Volume The Reciprocal Space, Wigner–Seitz Cell, Brillouin Zones and The Origin of Bands, Bands, Band Gaps, Free Electron Approximation and Tight Binding Approximation, Material Phenomena Explained using Theories Developed, Superconductivity and The Bose–Einstein Statistics.

Nanomaterials: Physics of Nano-Scale Materials, Classes and fundamentals, properties, synthesis and characterization, Carbon nanotubes: Properties, synthesis and applications, Polymer/CNT, ceramic/CNT, metal/CNT reinforced composite materials.

Graphene: Properties, synthesis and applications, Polymer/graphene, ceramic/ graphene, metal/ graphene reinforced composite materials, Carbon nanofiber and its applications, Carbon foams, Carbon materials for Li-ion rechargeable batteries

Recommended books:

1. Prathap Haridoss. *Physics of Materials: Essential Concepts of Solid-State Physics*
2. Michio Inagaki, Feiyu Kang, Masahiro Toyoda, Hidetaka Konno. *Advanced Materials Science and Engineering of Carbon.*

ME-516	Advanced Solids Mechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Learn about the elastic and plastic behaviour of material and evaluate stress invariants, principal stresses and their directions
CO2	Determine strain invariants, principal strains and their directions
CO3	Develop constitutive relationships between stress and strain for linearly elastic solid
CO4	Analyze theories of failure and design components for safe operation
CO5	Examine the properties of ideally plastic solid and apply the concepts of energy methods in solving structural problems.

Introduction: Basic Concepts in Mechanics, Basic Equations in Mechanics, Classification of the Response of Materials, Solution to Boundary Value Problems.

Mathematical Preliminaries: Overview of Algebra of vectors, Algebra of second order tensors, Algebra of fourth order tensors , Eigen values, eigenvectors of tensors, Transformation laws, Scalar, vector, tensor functions, Gradients and related operators, Integral theorems.

Kinematics : Deformation Gradient, Lagrangian and Eulerian description, Displacement, velocity and acceleration, Transformation of curves, surfaces and volume, Properties of the deformation tensors, Strain Tensors, Normal and shear strain, Homogeneous Motions, Compatibility condition.

Traction and Stress: Traction vectors and stress tensors, Normal and shear stresses, Principal stresses and directions, Stresses on a Octahedral plane, Examples of state of stress, Other stress measures Balance Laws: Conservation of Mass, Conservation of momentum.

Constitutive Relations: Definition of elastic process , Restrictions on constitutive relation, Isotropic Hooke's law, Material parameters, Restriction on material parameters, Internally constraint materials, Orthotropic Hooke's law.

Boundary Value Problem: Formulation: Formulation of boundary value problem, Techniques to solve boundary value problems Bending of Prismatic Straight Beams: Symmetrical bending, Asymmetrical bending, Shear center.

End Torsion of Prismatic Bars: Twisting of thick walled closed section, Twisting of solid open section, Twisting of hollow section.

Bending of Curved Beams: Winkler-Bach formula for curved beams; 2D Elasticity solution for curved beams.

Beam on Elastic Foundation: General formulation, Example 1: Point load, Example 2: Concentrated moment, Example 3: Uniformly distributed load

Recommended books:

1. Srinath L S. *Advanced Mechanics of Solids*. McGraw Hill Education, New Delhi, 2009.
2. Chadwick P. *Continuum Mechanics: Concise Theory and Problems*. Dover Publications, Inc., New York, 1999.
3. Gurtin M.E. *An Introduction to Continuum Mechanics*, volume 158 of *Mathematics in Science and Engineering*. Academic Press, San Diego, 1970.
4. Kellogg O.D. *Foundations of potential theory*. verlag von julius springer, Berlin, 1929.
5. Sadd M.H. *Elasticity: Theory, Applications and Numerics*. Academic Press, New Delhi, 2005.
6. Ogden R.W. *Non-linear elastic deformations*. Dover publications, New york, 1997.

ME-517	**Automotive Design**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the legislation regarding automobiles in India and abroad
CO2	Design Considerations towards Structure, Suspension, Transmission and Vehicle Dynamics of an automobile
CO3	Understanding of propulsion systems
CO4	Application of CAD and CAM
CO5	Case study and awareness regarding participation in national and international competitions.

Socio Economic Aspect of Automotive Mobility Engineering, Safety, Environment and Sustainability Issues. Requirements of Passenger and Commercial Vehicles. Design Considerations for Structure, Suspension, Transmission and Vehicle Dynamics. Study of Different Power Plants Used in Automobiles; Internal Combustion Engines, Battery System and Fuel Cell Technology. Understanding and Application of Computer Aided Engineering Hardware and Software. Application of Renewable Energy in Next Generation Automobiles. Role of Autonomous and Smart Vehicles.

Case Study Regarding Design and Analysis of Automobiles with Respect to Different National and International Competitions.

Recommended books:

1. Crouse, William H., and William Harry Crouse. *Automotive Mechanics*. Tata McGraw-Hill Education, 10th Ed., 2007
2. Bosch, Robert. *Automotive Electrics, Automotive Electronics*. Wiley, 2007.
3. Ehsani, Mehrdad, YiminGao, Stefano Longo, and KambizEbrahimi. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*. CRC press, 2018.

ME-518	Basic Biomechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the role of mechanics in physiology and introduction to biomechanics
CO2	To learn constitutive and decoupling equations to describe segmental movement
CO3	To understand the internal and external flows/deformations, analogous study
CO4	Introduction to different types of muscles and their functioning.

Introduction to Biomechanics. Historical sketch and scope; Mechanics in Physiology; Contributions of Biomechanics to Mechanics.

Segmental movement and vibrations; Generalized Coordinates, Lagrange's Equations, Normal Modes of Vibration, Decoupling of Equations of Motion, Muscle Forces, Segmental Movement and Vibrations, Systems with Damping and Fluid Dynamic Loads, Sufficient Conditions for Decoupling Equations of System with Damping.

Constitutive equations: Application to solids and fluids in biomechanics; Stress, Strain, Strain Rate, Constitutive Equations, The Non viscous Fluid, The Newtonian Viscous Fluid, The Hookean Elastic Solid, The Effect of Temperature, Materials with More Complex Mechanical Behavior, Viscoelasticity, Response of a Viscoelastic Body to Harmonic Excitation, Use of Viscoelastic Models,Methods of Testing, Mathematical Development of Constitutive Equations.

Description of internal deformation and forces; Use of Curvilinear Coordinates, Description of internal Forces, Work and Strain Energy, Calculation of Stresses from the Strain Energy Function, Complementary Energy Function, Rotation and Strain.

External Flow: Fluid dynamic forces acting on moving bodies; Flow Around an Airfoil, Flow Around Bluff Bodies, Steady-State Aeroelastic Problems, Transient Fluid Dynamic Forces Due to Unsteady Motion, Flutter, Kutta-Joukowski Theorem, The Creation of Circulation Around a Wing, Circulation and Vorticity in the Wake, Vortex System Associated with a Finite Wing in NonstationaryMotion, Thin Wing in Steady Flow, Lift Distribution on a Finite Wing, Drag.

Flying and swimming; Comparing Birds and Insects with Aircraft, Forward Flight of Birds and Insects, Hovering and Other Modes of Motion, Aquatic Animal Propulsion, Stokeslet and Dipole in a Viscous Fluid, Motion of Sphere, Cylinder, and Flagella in Viscous Fluid, Resistive-Force Theory of Flagellar Propulsion, Theories of Fish Swimming, Energy Cost of Locomotion, Cell Movement.

Skeletal muscle; The Functional Arrangement of Muscles, The Structure of Skeletal Muscle, The Sliding Element Theory of Muscle Action, Single Twitch and Wave Summation, Contraction of Skeletal Muscle Bundles, Hill's Equation for Tetanized Muscle, Hill's Three- Element Model, Hypotheses of Cross-Bridge Theory, Evidences in Support of the Cross-Bridge Hypotheses, Mathematical Development of the Cross-Bridge Theory, Constitutive Equation of the Muscle as a Three-Dimensional Continuum,

Heart Muscle; The Difference Between Myocardial and Skeletal Muscle Cells, Use of the Papillary or Trabecular Muscles as Testing Specimens, Use of the Whole Ventricle to Determine Material Properties of the Heart Muscle, Properties of Unstimulated Heart Muscle, Force, Length, Velocity of Shortening, and Calcium Concentration Relationship for the Cardiac Muscle, The Behavior of Active Myocardium According to Hill's Equation and its Modification, Pinto's Method, Micromechanical Derivation of the Constitutive Law for the Passive Myocardium.

Smooth Muscles; Types of Smooth Muscles, The Contractile Machinery, Rhythmic Contraction of Smooth Muscle, The Property of a Resting Smooth Muscle: Ureter, Active Contraction of Ureteral Segments, Resting Smooth Muscle: Taenia Coli, Other Smooth Muscle Organs.

Bone and Cartilage; Bone as a Living Organ, Blood Circulation in Bone, Elasticity and Strength of Bone, Viscoelastic Properties of Bone, Functional Adaptation of Bone, Cartilage, Viscoelastic Properties of Articular Cartilage, The Lubrication Quality of Articular Cartilage Surfaces,Constitutive Equations of Cartilage According to a Triphasic Theory, Tendons and Ligaments.

Books Recommended

1. Y. C. Fung, Biomechanics: Motion, Flow, Stress, and Growth, Springer, 1990.
2. Y. C. Fung, Biomechanics: Mechanical Properties of Living Tissues, 2nd Edition, Springer, 1993.
3. A. Freivalds, Biomechanics of the upper limbs: Mechanics, Modeling, and Musculoskeletal Injuries, CRC Press, 2004.
4. Fundamentals of Biomechanics, Duane Knudson, 2nd Edition, Springer, 2007.

ME-519	Computer Aided Design	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the basic fundamentals of computer aided design and manufacturing
CO2	To learn 2D & 3D transformations of the basic entities like line, circle, ellipse etc
CO3	To understand the different geometric modelling techniques like solid modelling, surface modelling, feature based modelling etc. and to visualize how the components look like before its manufacturing or fabrication
CO4	To learn the part programming, importance of group technology, computer aided process planning, computer aided quality control
CO5	To learn the overall configuration and elements of computer integrated manufacturing systems.

Introduction: Definitions, Historical Development. Nameable and Unnamable shapes, Explicit and Implicit Equations, Intrinsic Equations, Parametric Equations, Coordinate Systems.

Curves: Algebraic and Geometric Forms, Parametric space of a curve, Blending functions, Reparametrization, Truncating, Extending and subdividing, Space curve, Four point form, Straight lines, Spline Curves, Bezier Curves, B-spline Curves, Rational Polynomials, introduction to NURBS.

Geometric Transformation and Projection: Transformations: Translation, Rotation, Scaling Symmetry and Reflection, Homogeneous Transformations. Orthographic Projections, Axonometric Projections, Oblique Projections, Perspective Transformation.

Surfaces: Algebraic and Geometric form, Tangent and Twist Vectors, Normal, Parametric space of a surface, Blending Functions, Reparametrization of a surface patch, subdividing, Sixteen Point form, Four Curve Form, Plane surface, Cylindrical Surface, Ruled surface, Surface of Revolution. Bezier Surface, B-Spline Surface.

Solid Modelling Fundamentals: Topology of Closed Paths, Piecewise flat surfaces, topology of closed curved surfaces, Generalized Concept of boundary, Set theory, Boolean operators, Set- membership Classification, Euler operators, Formal Modelling Criteria.

Solid Model Construction: Graph Based methods, Boolean models, Instances and Parameterized Shapes, Cell Decomposition and spatial-Occupancy Enumeration, Sweep Representation, Constructive Solid Geometry, Boundary Representation. Assemble Modelling.

Data transfer formats: Neutral data format, IGES, STEP and XML.

Applications of Solid Models: Rapid Prototyping, FEM, Medical Applications**.**

Books Recommended

1. Geometric Modelling: Michael E. Mortenson, John Wiley, 2006
2. Mathematical Elements of Computer Graphics: Roger and Adams, McGraw Hill, 1994.
3. CAD CAM Theory and Practice: I. Zeid, McGraw Hill, 1994.

ME-520	Continuum Damage Mechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to explain the macroscopic through the concept of Continuum Damage Mechanics.
CO2	To properly estimate the value of damage when designing reliable structures it is necessary to formulate the damage phenomenon in terms of mechanics
CO3	To analyse various engineering problems using analytical and computational techniques.

Essentials of Continuum mechanics: Tensorial notation, stress, strain, invariants, equilibrium equations, Domain and validity of continuum damage mechanics, concept of representative volume element.

Phenomenological aspects of damage: Damage, measurement of damage, modeling of damage through effective area reduction, void volume fraction and stiffness reduction, representation ofdamage through different orders of tensors, concept of effective stress, hypothesis of strain equivalence, strain energy equivalence, and complementary strain energy equivalence.

Thermodynamics of damage: State variables, damage as state variables, first and second law of thermodynamics, thermodynamics potentials, dissipation potentials, constitutive equations, evolution equations.

Kinetic Laws of Damage Evolution: Unified formulation of damage laws, damage laws for brittle, quasi-brittle, ductile, creep, low cycle and high cycle fatigue.

Damage Analysis of Structures: Implementation of isotropic damage theory, case studies from literature.

Books Recommended

1. A Course on damage mechanics: Jean Lemaitre.
2. Continuum damage mechanics: S. Murakami.
3. Mechanics of solid materials: Jean Lemaitre and J. L. Chaboche.
4. An Introduction to damage mechanics: L. M. Kachanov.

5. Damage mechanics: Dusan Krajcinovic.
6. Damage mechanics: George Z. Voyiadjis and Peter I. Kattan.

ME-521	Control Theory and Applications	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Learn the basics of control systems and understand how to build the transfer functions of simple mechanical systems.
CO2	Understand the design of various controllers such as PID controller and predict the response of simple systems
CO3	Understand about gain and phase margin. Learn the concept of active vibration control
CO4	Design various mechanical systems and predicts its behaviour by plotting root locus diagram
CO5	Learn and apply the state space model to simple systems. Design and solve few problems by using digital control system.

Introduction to automatic controls. Modeling of flow, heat transfer and electrical, pneumatic and vibration systems. Block diagram and transfer function. Modeling of continuous systems. Extraction of reduced order models. Transient and frequency response evaluation using Laplace transform. Characteristics of hydraulic controller, pneumatic, electronic controller, electro-hydraulic and electro-pneumatic controllers. PID control. Stability Gain and phase margins. Control system design using root and compensation. Application to Machine tool, Boiler, Engine Governing, Aerospace, Active vibration control, etc. Auto-tuning. Sequence control, Logic diagram. Introduction to digital control, Implementation using computer. Introduction to control of MIMO systems. State Space modeling. Tutorials for control problems in these areas using MATLAB.

Books Recommended:

1. Gopal M, "*Modern Control System Theory*", John Wiley & Sons (16 May 1984)
2. Gopal M and Nagrath I.J, "*Control Systems Engineering*", New age international publishers (2007)
3. Ogata K, "*Modern Control Engineering (5th Edition)*", Prentice Hall International UK London (1997)

ME-522	Design of Fluid Film Bearings	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding of basic governing equations related to lubrication mechanisms
CO2	Understanding of different boundary conditions for fluid film bearings and their use
CO3	Understanding of analytical and numerical solutions of governing equations for fluid film bearings
CO4	Knowledge of different types of bearings such as porous, gas, hybrid bearings.

Mechanics of lubricant films and basic equations: Lubricant, Lubricant properties, Lubrication regimes, Viscosity index, Pertoff's Equation, Equation of continuity, momentum and energy, Generalized Reynolds Equation, Simplification of Full Reynolds Equation, Three different boundary conditions i.e. Full Sommerfeld Condition, Half Sommerfeld and Reynolds.

Thrust Bearings: Geometry, Infinite thrust bearing, Pressure distribution, Center of pressure, Load carrying capacity, Friction, Finite thrust bearing.

Journal Bearings: Geometry, Short and infinite long bearing, Pressure distribution, Load carrying capacity, Attitude angle, Friction, Adiabatic solution for journal bearing, Finite journal bearing.

Others types of Bearings: Analytical and numerical solutions of Hydrodynamic porous bearings, Hydrodynamic gas bearings, Hybrid bearing.

Case studies: Related to fluid film bearing problems

Books Recommended

1. Hamrock, Schmid, Jacobson. *Fundamentals of Fluid Film Lubrication*.
2. Khonsari and Booser. *Applied Tribology Bearing Design and Lubrication*
3. Cameron. *Principles of Lubrication*
4. Bhushan, B. *Principles and Applications of Tribology*
5. Fukao, Oshima, Takemoto, Dorell. *Magnetic Bearings and Bearingless Drives*.
6. Ghosh, Majumdar, Sarangi. *Theory of Lubrication.*

ME-523	Fracture Mechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To learn about the stress intensity factor approach, LEFM approach, CMOD approach and J integral fracture criteria
CO2	Having knowledge of various parameters related with fracture mechanics evaluation
CO3	Determining the safe designs for structures and components.

Linear elastic fracture mechanics- Energy approach and stress intensity factor approach. General yielding fracture mechanics. Concept of crack opening displacement and J integral fracture criteria. Evaluation of fracture mechanics parameters. Fracture safe designing of structures and machine components. Service failure analysis.

Books Recommended

1. Richard W. Hertzberg Deformation and Fracture Mechanics of Engineering Materials
John Wiley & Sons Inc 1995
2. S. D. Antolovich, “Fundamentals of Fracture Mechanics” Academic Pr 2009
3. A Saxena “Non-Linear Fracture Mechanics for Engineers” CRC Press 2009

ME-524	Heat Treatment and Surface Hardening	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of science & engineering
CO2	To apply and integrate the knowledge of phase transformation to analyze the material behaviour
CO3	Ability to learn the basics of heat treatment and apply the concepts for processing of advanced materials.

Introduction: Definition (Materials tetrahedron perspective) –Aim & Theory of Heat Treatment (Why, How, What) -Structure of Metals and Alloys and Materials - Phase diagram and phase transformation, Relation between thermodynamics and Kinetics for phase transformation.

Phase transformation and heat treatment (Time and temperature influence): Concept of JKMA equation and TTT diagram -Heat treatment time and temperature and microstructure/property developed, CCT diagram from TTT diagram and experimental data and its implication to heattreatment, Some heat treatments, like annealing, normalizing, hardening, tempering of steel on the basis of TTT and CCT diagram and properly-microstructure correlation, Introduction to Precipitation hardening.

Introduction to Heat Treatment of Alloys(Al-alloy and Steel): Theory of Heat Treatment (Why, How, What), Thermodynamic basis for heat treatment of alloys, Phase diagram and phase transformation in alloys, Choice of composition and temperature for heat treatment and related phase transformation in Al-alloys, Choice of composition and temperature for heat treatment and related phase transformation in steel, Theory of Heat Treatment-Hardenability and Jominy test, Case hardening of Alloy systems for Steels

Books Recommended

1. Principles of Heat Treatment of Steels by R.C. Sharma
2. Phase Transformations in Metals and Alloys by D.A. Porter and K.E. Easterling (Taylor and Francis)
3. Engineering Physical Metallurgy and Heat Treatment by Y. Lakhtein (Mir Publisher)

ME-525	**Machine Tool Design**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To learn the importance of machine tool design in metal cutting and systematic approach to design machine tools
CO2	To design the structural components in order to achieve desired elastic and fatigue properties
CO3	Use of design software to design the machine tools
CO4	To learn the working principle and recent developments in the area of CIMS and CNC manufacturing systems.

Design requirements of machine tools, Design approach for machine tools, identification and quantification of objectives and constraints in machine tool design. Estimation of power requirements and selection of motor for metal cutting machine tool spindles. Design of gearbox, spindle and guide-ways. Principles of design of structural components, namely, head stock, tail stock, carriage, table, knee, column and over arms to achieve desired static and fatigue strength, stiffness, dynamic characteristics and other requirements. Exercises on the design of machine tools using existing CAD software packages.

Introduction to computer integrated manufacturing systems and CNC machine tools. Design/selection of linear motion systems, ball, screws, CNC feedback devices, controllers, feed drives and servomotors for CNC machine tools.Recent developments in CNC and other machine tools.

Books Recommended

1. Devris W R, “Analysis of Material Removal Processes”, Springer – Verlag, 1992.
2. N Acherkan , “Machine Tool Design” , Volume- 1-4, MIR Publishers, Moscow, 1969
3. Mishra P K, “Non Conventional Machining”, Narosa Publishing House, New Delhi, 1977Edition.
4. Panday P C, Shan H S, “Modern Machining Processes”, Tata McGraw Hill PublishingCompany Limited, New Delhi, 1980 Edition.
5. Schey A, John, “Introduction to Manufacturing Processes”, McGraw Hill Book Company,New York, 1987.
6. Jain R K, “Production Technology”, Khanna Publishers Delhi, 1995.
7. HMT Bangalore, “Production Technology”, Tata McGraw Hill, New Delhi, 1980.

ME-526	Material Characterization and Properties	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of mathematics, science & engineering
CO2	To apply and integrate knowledge of various material characterization techniques for development of advanced materials
CO3	Ability to learn the basics of material properties and apply the concepts for characterization of advanced materials.

Light microscopy, X-ray diffraction methods, Transmission electron microscopy, Scanning electron microscopy, scanning tunneling microscopy, scanning probe microscopy, X-ray spectroscopy for elemental analysis, Electron spectroscopy for surface analysis, SIMS for surface analysis, Vibrational spectroscopy for molecular analysis, DTA and DSC analysis, Thermogravimetry.

Books Recommended

1. Materials Characterization: Introduction to Microscopic and Spectroscopic Methods – Yang Leng, John Wiley & Sons.
2. Materials Characterization Techniques-Sam Zhang, Lin Li, Ashok Kumar, CRC press.

ME-527	Materials and Environment	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the importance of materials and interrelationship between Materials, Energy, Emissions and Environment
CO2	Carryout Life Cycle Assessment (LCA), Eco Audits using various methods
CO3	Understand the importance of materials selection in the Mechanical Design process and use Material property charts, Material Indices for selecting materials for various types of mechanical systems
CO4	Introduce the concept of Ecological Selection of Materials.

Introduction Material Dependence: Introduction and synopsis, Materials: a brief history, Learned dependency: the reliance on nonrenewable materials, Materials and the environment.

Resource Consumption & its drivers: Resource consumption, Exponential growth and doubling times, Reserves, the resource base, and resource life, Summary and conclusion.

The Materials Life Cycle: The material life cycle, Life-cycle assessment: details and difficulties, Streamlined LCA, The strategy for eco-selection of materials.

End of First Life- A Problem or a resource: What determines product life, End-of-first-life Options, The problem of packaging, Recycling: resurrecting materials.

Eco Data-Values, Sources, precision: Data precision- recalibrating expectations, The eco-attributes of materials, Energy and CO2 footprints of energy, transport, and use, Exploring the data: property charts.

Eco Audits & Eco Audit Tools: Introduction and synopsis, Eco-audits, Computer-aided eco-auditing, Case Studies.

Selection Strategies: Introduction, The selection strategy: choosing a car, Principles of materials selection, Selection criteria and property charts, Resolving conflicting objectives: tradeoff methods.

Eco-Informed Material Selection: Which bottle is best? Selection per unit of function, Crash barriers: matching choice to purpose, Deriving and using indices: materials for light, strong shells, Heating and cooling, Transport.

Sustainability- Living on Renewables: The ecological metaphor, Sustainable energy, sustainable materials, Future options.

Books Recommended

1. Ashby M, "Materials & the Environment- Eco-Informed Material Choice", Butterworth-Heinemann (2019)
2. Ashby M, "Materials and Sustainable Development", Butterworth-Heinemann (2016)
3. Ashby M, "Materials Selection in Mechanical Design", Third Edition, Elsevier, Indian Edition, (2005)
4. Ashby M and Johnson K, "Materials & Design, 2nd Edition- The Art & Science of Material Selection in Product Design", Butterworth-Heinemann (2009)

ME-528	Materials and Sustainable Development	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the importance of materials and interrelationship between Materials, Energy, Emissions and Environment
CO2	Carryout Life Cycle Assessment (LCA), Eco Audits using various methods
CO3	Understand the meaning and importance of sustainable development, assessment methods/techniques for sustainable development with various case studies
CO4	Evaluate Materials supply chain risk and understand concept of CSR.

Introduction Material Dependence: Introduction and synopsis, Materials: a brief history, Learned dependency: the reliance on nonrenewable materials, Materials and the environment.

Resource Consumption & its drivers: Resource consumption, Exponential growth and doubling times, Reserves, the resource base, and resource life, Summary and conclusion.

The Materials Life Cycle: The material life cycle, Life-cycle assessment: details and difficulties, Streamlined LCA, The strategy for eco-selection of materials.

Eco Data-Values, Sources, precision: Data precision- recalibrating expectations, The eco-attributes of materials, Energy and CO2 footprints of energy, transport, and use, Exploring the data: property charts.

Eco Audits & Eco Audit Tools: Introduction and synopsis, Eco-audits, Computer-aided eco- auditing, Case Studies.

Sustainable Development: Introduction, Definitions, Triple Bottom Line Approach, Articulations of sustainable development, Assessing sustainable development, layered approach to assess sustainable development, Tools for assessment, Defining objective, stake holder analysis, fact finding, synthesis.

Materials Supply chain risk: Emerging constraints on materials sourcing and usage, price volatility risk, monopoly of supply and geo political risk, conflict risk, legislation & regulation risk, other risks.

Corporate Sustainability & materials: Introduction, Corporate social responsibility & sustainability reporting, Case Studies on Corporate SR's.

Case Studies on Sustainable development: Biopolymers to replace oil based plastics, Wind Farms, Electric Cars, Solar PV for Low Carbon power, Bamboo as sustainable building material.

Books Recommended

1. Ashby M, "Materials and Sustainable Development", Butterworth-Heinemann (2016)
2. Ashby M, "Materials & the Environment- Eco-Informed Material Choice", Butterworth Heinemann (2019)
3. Ashby M, "Materials Selection in Mechanical Design", Third Edition, Elsevier, Indian Edition, (2005)
4. Ashby M and Johnson K, "Materials & Design, 2nd Edition- The Art & Science of Material Selection in Product Design", Butterworth-Heinemann (2009)

ME-529	Mechanics of Composite Materials	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of mathematics, science & engineering
CO2	To apply and integrate knowledge of different processes of composite fabrication for making advanced composite materials
CO3	Ability to learn the basics of composite mechanics and apply the concepts for making lightweight composites with high strength.

Introduction: Definition of composite, load transfer mechanism, classification of composites, advantages and applications of composites, fibers, matrix materials and their properties.

Basic concepts of solid mechanics: General state of stress, equilibrium equations, tensors – constitutive equations, plane stress, plane strain and strain energy concept.
Micromechanics of Composites: 3-D constitutive equations: Generalized Hooke's Law - orthotropic, transversely isotropic and isotropic materials. Engineering constants, stiffness and compliance matrix, stress and strain transformation, transformed stiffness and compliance matrix. Lamina stress-strain relations in principal and global coordinates. Thermal Stress.

Micromechanics of Composites: Basic concepts, fiber packing geometry, micromechanical methods for prediction of properties of fiber-reinforced composites – Longitudinal, transverse and shear moduli, Poisson's ratios, tensile and compressive strength.

Composite Laminates: Basic concepts of classical lamination theory (CLT) – laminate stress. Laminate stiffness – A-B-D matrix, and their implications.

Failure Theories: Application of theories of failure to fiber – reinforced composites, failure mechanisms, maximum stress, maximum strain, Tsai-Hill theory, Tsai-Wu theory of failure. Comparison of failure criteria.
Dynamic behavior: Linear viscoelastic behavior, creep and relaxation, differential equations ands pring dashpot models. Complex modulus, elastic-viscoelasitc correspondence principle, longitudinal, flexural vibrations of composite beams and transverse vibrations of laminations, analysis of damping in composites.

Books Recommended

1. Broutman L J and Krock R H "Modern Composite Materials", Addison Wesley Publishing Company, 1967.
2. Jones R M "Mechanics of Composite Materials", Scripta Book Company, 1975.
3. Herkovic C T "Mechanics of Fibres Composites", University of Virginia, John Wiley and Sons, Inc, 1998.

4. Tsai Stephen W "Introduction to Composite Materials", Technomic Publishing Company Inc., 1980.
5. 5. Gibson R F, "Principles of Composites Materials Mechanics", McGraw Hill International Edition, New York, 1994.
6. Hyer M W, "Stress analysis of Fiber-Reinforced Composites Materials", WCB McGraw Hill, Boston, 1997.
7. Halpin J C, "Primer on Composite Materials Analysis", Technomic Publishing Company Inc, Lanchester, 1992

ME-530	Methods of Analytical Dynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the basic fundamentals of mechanics and governing laws to describe the force and motion systems
CO2	To learn different laws and principles in analytical mechanics and different motions of coordinates and reference frames
CO3	Behaviour and stability of dynamical and non-autonoums systems.

Fundamentals of Newtonian Mechanics: Historical survey of Mechanics, Newton's Laws, Impulse and Momentum, Moment of a Force and Angular Momentum, Work and Energy, Energy Diagrams, Systems of Particles, The Two-Body Central Force Problem, The Inverse Square Law, Orbits of Planets and Satellites, Scattering by a Repulsive Central Force.

Fundamentals of Analytical Mechanics: Degree of Freedom. Generalized Coordinates, System with Constraints, The Stationary Value of a Function, The Stationary Value of a Definite Integral, The Principle of Virtual Work, D'Alembert's Principle, Hamilton's Principle, Lagrange's Equations of Motion, Lagrange's Equations for Impulsive Forces, Conservation Laws, Routh's Method for the Ignoration of Coordinates, Rayleigh's Dissipation Function, Hamiltion's Equations.

Motion Relative to Rotating Reference Frames: Transformation of Coordinates, Rotating Coordinates Systems, Expressions for the Motion in Terms of Moving Reference Frames, Motion Relative to the Rotating earth, Motion of a Free Particle Relative to the Earth, Foucault's Pendulum.

Rigid Body Dynamics: Kinematics of a Rigid Body, The Linear and Angular Momentum of a Rigid Body, Translation Theorem for the angular Momentum, The Kinetic Energy of a Rigid Body, Principle Axes, Moment-Free Inertially Symmetric Body, General Case of a Moment-Free Body, Motion of a Symmetric Top, The Lagrangian Equation of Quasi-Coordinates, The Equations of Motion Referred to an Arbitrary System of Axes, The Rolling of a Coin.

Behaviour of Dynamical Systems. Geometrical Theory: Fundamental Concepts, Motion of Single-Degrees-of Freedom Autonomous Systems about Equilibrium Points, Conservative Systems. Motion in the Large, The Index of Poincaré, Limit Cycles of Poincaré.

Stability of Multi-Degree-of-Freedom Autonomous Systems: General Linear Systems, Linear Autonomous Systems, Stability of Linear Autonomous Systems. Rourh-Hurwitz Criterion, The Variational Equations, Theorem on the First-Approximation Stability, Variation from Canonical Systems. Constant Coefficients, The Liapunov Direct Method, Geometrical Interpretation of the Liapunov Direct Method, Stability of Canonical Systems, Stability in the Presence of Gyroscopic and Dissipative Forces, Construction of Liapunov Function for Linear Autonomous Systems.

Non-autonomous Systems: Linear Systems with Periodic Coefficients. Floquet's Theory, Stability of Variational Equations with Periodic Coefficients, Orbital Stability, Variuation from Canonical Systems, Periodic Coefficients, Second-Order Systems with Periodic Coefficients, Hill's Infinite determinant, Mathieu's Equation, The Liapunov Direct Method.

Analytical Solution by Perturbation Techniques: The Fundamental Perturbation Technique, Secular Terms, Lindstedt's Methods, The Krylov-Bogoliubov-Mutroposlsky (KBM) Method, A Perturbation Technique Based on Hill's Determinations, Periodic Solutions of Non-autonomous Systems. Duffing's Equation, The Method of Averaging.

Transformation Theory. The Hamilton-Jacobi Equations: The Principle of Least Action, Constant Transformations, Further Extensions of the Concept of Contact Transformations, Integral Invariants, The Langrange and Poisson Brackets, Infinitesimal Contact Transformations, The Hamilton-Jacobi Equation, Separable Systems, Action and Angule Variables, Peturbation Theory.

Books Recommended

1. Leonard Meirovitch, "Methods of Analytical Dynamics", First South Asian Edition, Dover Publications Inc., 2007.
2. H. Goldstein, Classical Mechanics, Pearson, 2011.
3. Francis B. Hildebrand, *Methods of Applied Mathematics*, 2nd Edition, Dover PublicationsInc., 2002.

ME-531	Modal Analysis of Mechanical System	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Learn the basics of mechanical vibrations and predict the modal-model i.e., natural frequencies, mode shapes and damping coefficient of simple systems. Understand the concept of state- space model. Also, learn the concept of frequency response function (FRF)
CO2	Understand the vibration measuring instruments and predict the FRF at different excitations
CO3	Design the FRF for Single and multi-degree of freedom systems
CO4	Understand the modal-model, response model, spatial models, mobility skeletons and system models. Learn the application of experimental modal analysis on mechanical systems.

Overview: Applications of Modal Testing, Philosophy of Modal Testing, Summary of Theory, Summary of Measurement Methods, Summary of Modal Analysis Processes, Review of test procedures, and levels, Terminology and Notation.

Theoretical Basis: Single-Degree-of Freedom (SDOF) system theory, Presentation and properties of FRF Data for SDOF system, Undamped Multi-Degree-of Freedom (MDOF) system, MDOF systems with proportional damping, MDOF systems with structural (hysteretic) damping – General case, MDOF systems with viscous damping – general case, Modal Analysis of Rotating Structures, Complex Modes, Characteristics and presentation of MDOF FRF Data. Non-sinusoidal Vibration and FRF properties.

Response Function Measurement Techniques: Basic measurement system, Structure Preparation, Excitation of the Structure, Transducers and amplifiers, Analyzers, Digital signal processing, use of different excitation signals, calibration, mass cancellation, rotational FRF measurement, measurements on non-linear structures, multi-point excitation methods, measuring
FRFs and ODSs using the scanning LDV.

Modal Parameter Extraction Methods: Preliminary checks of FRF data, SDOF modal analysis, methods, MDOF modal analysis in the frequency domain (SISO), global modal analysis in the time domain, modal analysis of non-linear structures, concluding comments.

Derivation of Mathematical Models: Modal models, refinement of modal models, display of modal model, response model, spatial models, mobility skeletons and system models.
Applications: Comparison of and correlation of experiment and prediction, adjustment or updating of models, coupled and modified structure analysis, response prediction and force determination, test planning.

Books Recommended

1. Ewins D J, "Modal Testing: Theory and Practice" Research Studies Press Ltd 1985.
2. He and fu "Modal Analysis" Elsevier Science & Technology 2001.
3. J M M Silva & N M M Maia "Modal Analysis and Testing" Kluwer Academic Publishers Group 1999.
4. G Conciauro, M Guglielmi, R Sorrentino "Advanced Modal Analysis" John Wiley & Sons 2000.

ME-532	Modern Control Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the physical significance of control systems
CO2	Dynamic response, mathematical modelling and analogy between different systems
CO3	To design and analyse different control systems
CO4	Characteristics and performance of feedback control systems and Introduction to digital control systems.

Introduction to Control Systems. Historical perspective leading to modern control engineering;

Mathematical Modeling of Dynamic Systems: Mechanical, Electrical, Fluid, Thermal Systems, etc. State variable models;

Dynamic response: Transient and Steady-State Response Analyses

Characteristics and performance of feedback control systems:

Stability in the frequency and time domains: Lyapunov stability;

Control systems analysis and design: Root-locus method, frequency-response method;

Control systems analysis and design in state space: Controllability and Observability, Pole placement using feedback, the separation principle and estimator design, PID Controllers

Digital control systems: Sampled-data systems, stability analysis, compensation, implementation of digital controllers;

Case studies: Computer simulation of dynamic systems.

Books Recommended

1. G. F. Franklin, J. D. Powell, A. Emami-Naeini, Feedback Control of Dynamic Systems, Pearson Education Inc., 2002.
2. R. C. Dorf, R. H. Bishop, Modern Control Systems, Addison-Wesley Longman Inc. 1998.
3. B. C. Kuo, Feedback Control Systems, Prentice Hall.
4. K. Ogata, Modern Control Engineering, Prentice Hall.
5. EroniniUmez-Eronini, System Dynamics & Control, Brooks/ Cole Publishing Company,1999.
6. N. S. Nise, Control Systems Engineering, John Wiley & Sons (Asia) Pte. Ltd., Singapore,2004.
7. Bernard Friedland, Control Systems Design, McGraw-Hill.

8. Graham C Goodwin, Stefan F Graebe, Mario E Salgado, Control System Design, Pearson Education Inc., 2001.
9. Karnopp, Margolis, Rosenberg, System Dynamics: Modeling and Simulation of Mechatronic Systems, Fourth Edition, Wiley (Higher education), 2005.
10. Amalendu Mukherjee, Ranjit Karmakar and Arun Kumar Samantaray, Bond Graph in Modeling, Simulation and Fault Identification, I. K. International Publishing House Pvt. Ltd, 2006.
11. NPTEL lectures on modern control engineering

ME-533	Nonlinear Finite Element Method	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	understanding of the practical use of computer programs for numerical simulation of nonlinear finite element analysis
CO2	to learn about applications of finite element procedures to nonlinear Structural / Solid Mechanics problems
CO3	The formulation of finite element procedure to solve boundary value problems involving above nonlinearities
CO4	To expose the student to implementing algorithms in finite element codes and debugging them through example problems
CO5	The student will acquire the skill to implement the algorithms via user-defined subroutines in general purpose finite element codes like ANSYS and ABAQUS.

Introductory lecture: review of Linear Finite Element Methods, presentation of course content.

Demonstration lecture on Abaqus: Installation and running the software, geometric modelling, writing user subroutine – UMAT.

Review of continuum Mechanics: Tensor algebra & Calculus, Kinematics, Stress measures, Clausius Duhem inequality, Objectivity with examples, objective rates used in non-linear finite element computations – comparisons using examples.

Variational calculus – formulating linear and non-linear mechanics problems, Introduction to Directional derivative.Directional derivative – variation of various stress and strain measures, Introduction to Linearization.

Introduction to Total and Updated Lagrangian formulations – derivation of weak forms, Solution methods – Newton Raphson method and variants.

Updated Lagrangian formulation: Discretized FE equations using IsoParametric formulation Restrictions on the constitutive equations imposed by frame indifference and thermodynamics.

Constitutive equations for hyperelasticity (with and without incompressibility), rate dependent and independent plasticity in metals and Crystal plasticity.

Linearization of constitutive equations to be used in weak forms, and FE discretisation: Example – Compressible, Neo-Hookean material (other constitutive formulations may also be taken up here).

Geometric and material stiffness matrices – details of implementation, writing User subroutine UEL in Abaqus.

Convergence measures: rate of convergence, Patch test
Geometric and material stiffness matrices: discussion on rank, deficiency and implementation details.

Discussion of techniques: incompressibility condition. Gauss Quadrature, Reduced integration, Locking issues.

Books Recommended

1. Ted Belytschko, Nonlinear Finite Elements for Continua and Structures. John Wiley & Sons, Ltd..K. J. Bathe, Finite Element Procedures. Prentice – Hall Ltd.
2. M. A. Crisfield, Non-linear Finite Element Analysis: Essentials (Volume 1), John Wiley & Sons, Ltd.
3. M. A. Crisfield, Non-linear Finite Element Analysis: Advanced topics (Volume 2), John Wiley & Sons, Ltd.

ME-534	Nonlinear Systems	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	The ability to understand the characteristics of various types of nonlinearities present in physical systems
CO2	The ability to carry out the stability analysis of non-linear control systems
CO3	The ability to carry out the analysis and design of control systems
CO4	The ability to analyze the effect sampling on stability, controllability and observability
CO5	The ability to design digital controllers for industrial applications.

Introduction: Nonlinear Models and Nonlinear Phenomena, Examples Pendulum Equation, Tunnel-Diode Circuit, Mass-Spring System, Negative-Resistance Oscillator, Artificial Neutral Network, Adaptive Control, Common Nonlinearities.

Second-Order Systems: Qualitative Behaviour of linear Systems, Multiple Equilibria, Qualitative Behaviour Near Equilibrium Points, Limits Cycles, Numerical Construction of Phase Portraits, Existence of Periodic Orbits, Bifurcation.

Fundamental Properties: Existence and Uniqueness, Continuous Dependence on Initial Conditions and Parameters, Differentiability of Solutions and Sensitivity Equations, Comparison Principle.

Lyapunov Stability: Autonomous Systems, The Invariance Principle, Linear Systems and Linearization, Comparison Functions, Non-autonomous Systems, Linear Time-Varying Systems, and Linearization, Converse Theorems, Boundedness and Ultimate Boundedness, Input-to-State Stability.

Input-Output Stability: L Stability, L Stability of State Models, L2 Gain, Feedback Systems: The Small-Gain Theorem.

Passivity: Memory less Functions, State Models, Positive Real Transfer Functions, L2 and Lyapunov Stability, Feedback Systems: Passivity Theorems.

Feedback Control: Control Problems, Stabilization via Linearization, Integral Control, Integral Control via Linearization, Gain Scheduling.

Feedback Linearization: Motivation, Input-Output Linearization, Full-State Linearization, State Feedback Control.

Nonlinear Design Tools: Sliding Mode Control, Lyapunov Redesign, Back-stepping, Passivity-Based Control, High-Gain Observers.

Books Recommended

1. Hassan K. Khalil, Nonlinear Systems, Second Edition, Prentice Hall Inc., 2002.
2. Ali H. Nayfeh, The Method of Normal Forms, Wiley, 2011.
3. Ali H. Nayfeh, Introduction to Perturbation Techniques, Wiley-VCH Verlag GmbH.
4. D. T. Mook, Ali H. Nayfeh, Nonlinear oscillations, Wiley-VCH Verlag GmbH.
5. Leonard Meirovitch, Methods of Analytical Dynamics, First South Asian Edition, Dover
6. Publications Inc., 2007.

ME-535	Robotics: Mechanics and Control	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the importance of robotics and its impact on human safety, quality of life, economy, environment, etc.; basics of open ended type of Robotic manipulators
CO2	Understanding of kinematics and dynamics of open ended robotic mechanisms; Fixing frames using the Denavit-Hartenberg convention, Jacobian, singularity, Newton-Euler formulations for dynamics of rigid body systems
CO3	Ability to formulate, derive, analyse, design and synthesize kinematics and dynamics of open ended robotic mechanisms
CO4	Understand and apply detailed concepts relating to various actuators, sensors, and their integration with drives and signal conditioning for robotics
CO5	Understanding concepts of feedback control of robotic manipulators based on modern control theory; PID Control; and applying them to Joint control and trajectory control.

Introduction to Robotics

Kinematics and Dynamics of Robotic linkages (open ended type manipulators): Frames, Transformations: Translation and rotation, Denavit-Hartenberg parameters, Forward and Inverse Kinematics, Jacobian, Dynamics: Equations of motion, Newton-Euler formulation.

Sensors and actuators: Strain gauge, resistive potentiometers, Tactile and force sensors, tachometers, LVDT, Piezo electric accelerometer, Hall effect sensors, Optical Encoders, Pneumatic and Hydraulic actuators, servo valves, DC motor, stepper motor, drives.

Control of Manipulators: Feedback control of II order Linear systems, Joint control, Trajectory control, Controllers, PID control.

Books Recommended

1. John J. Craig, Introduction to Robotics: Mechanics and Control, Addison-Wesley, 2005.
2. Tsuneo Yoshikawa, Foundations of Robotics, MIT Press, 1990.
3. Saeed B. Niku, Introduction to Robotics: Analysis, Systems, Applications, Pearson Education Inc., 2001
4. Spong M. W., and Vidyasagar M., Robot Dynamics and Control, John Wiley & Sons, 1989.
5. Murray R. M., et al, A Mathematical Introduction to Robotic Manipulation, CRC Press, 1994.
6. Waldron K. J., and Kinzel G. L., Kinematics, Dynamics and Design of Machinery, John Wiley & Sons, 2004.
7. EroniniUmez-Eronini, System Dynamics & Control, Brooks/ Cole Publishing Company, 1999.
8. Amalendu Mukherjee, Ranjit Karmakar and Arun Kumar Samantaray, Bond Graph in Modeling, Simulation and Fault Identification, I. K. International Publishing House Pvt.

ME-536	Soft Computing Techniques	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To solve differential equations using numerical methods

CO2	Use of MATLAB for numerical analysis and programming
CO3	Use of optimization methods and SIMULINK for programming and scientific computations.

Simple Calculations with MATLAB, Writing Scripts and Functions, Plotting Simple Functions, Loops and Conditional Statements, Root Finding, Interpolation and Extrapolation, Matrices, Numerical Integration

Solving Differential Equations: Some Basics of ODE Integration, Linear PDE, Nonlinear PDE Simulations and Random Numbers.

Optimization Methods: Linear Programming, Dynamic Programming, Network Analysis.

SIMULINK: Introduction to SIMULINK Engineering and Scientific Computations Using SIMULINK, Engineering and Scientific Computations Using SIMULINK

Books recommended

1. S.R. Otto and J.P. Denier, An Introduction to Programming and Numerical Methods in MATLAB. Springer-Verlag London Limited 2005
2. Steven T. Karris, Numerical Analysis Using MATLAB® and Spreadsheets Orchard Publications 2005
3. Sergey E. Lyshevski, Engineering and Scientific Computations Using MATLAB, Pave1 Solin Partial Differential Equations and the Finite Element Method, John Wiley & Sons, Inc., Publication

ME-537	Theory of Elasticity	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to derive the governing equations for 2D and 3D elastic problems
CO2	Be able to analysis of stress and deformation
CO3	To apply the basic field equations of linear elastic solids in various boundary value problems
CO4	To solve these problems with various solution methodologies.

Analysis of Stress: Concept of Stress, Stress Components, Equilibrium Equations, Stress on a General Plane (Direction Cosines, Axis Transformation, Stress on Oblique Plane through a point, Stress Transformation), Principal Stresses, Stress Invariants, Deviatoric Stresses, Octahedral Stresses, Plane Stress, Stress Boundary Condition Problem.

Analysis of Strain: Deformations (Lagrangian Description, Eulerian Description), Concept of Strain, Strain Components (Geometrical Interpretation), Compatibility Equations, Strain transformation, Principal Strains, Strain Invariants, Deviatoric Strains, Octahedral Strains, Plane Strain, Strain Rates.

Stress-Strain Relations: Introduction, One-Dimensional Stress-Strain Relations (Idealized Time-independent and Time dependent stress-strain laws), Linear Elasticity (Generalized Hooke s Law), Stress-Strain Relationships for Isotropic and Anisotropic Materials (Plane stress and Plane Strain).

Basic Equations of Elasticity for Solids: Introduction, Stresses in Terms of displacements, Equilibrium Equations in terms of displacements, Compatibility equations in Terms of Stresses, Special cases of Elasticity equations (Plane Stress, Plane strain, Polar Coordinates), Principle of Superposition, Uniqueness of Solution, Principle of virtual work, Potential and Complementary energy, Variational Principles, St. Venant s Principle, Methods of analysis for Elastic Solutions, Elastic solutions by Displacement and stress Functions, Airys Stress Function (Plane stress, Plane strain, Polar Co-ordinates).

Torsion: Introduction, Circular shaft, Torsion of non-circular cross-section, St. Venant's theory, Warping function, Prandtl s stress function, Shafts of other cross-sections, Torsion of bars with thin walled sections.

Books Recommended

1. Mathematical Theory of Elasticity by I. S. Sokolnikoff.
2. Advanced Mechanics of Materials by Boresi.
3. Theoretical Elasticity by A. E. Green and W. Zerna.
4. Theory of Elasticity, Timoshenko, S.P., and Goodier, J.N., McGraw-Hill.

ME-538	**Theory of Plasticity**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to define stress and strain in 3D system for plastic region with related laws and problems
CO2	Be able to describe mechanism of plastic deformation from fundamentals of material science
CO3	To calculate true stress and strain in plastic deformation
CO4	To understand the physical interpretation of material constants in mathematical formulation of constitutive relationship
CO5	To solve analytically the simple boundary value problems with elasto-plastic properties
CO6	Be able to illustrate slip line field theory and their geometry and property.

Introduction to plasticity: Resolved shear stress & strain, Lattice slip systems, Hardening, Yield surface, Flow rule, Micro to Macro plasticity. Stresses and Strains: The Stress–Strain Behaviour, Analysis of Stress, Mohr's Representation of Stress, Velocity gradient and rate of deformation, Kinematics of large deformation, The Criterion of Yielding, Yielding of materials under complex stress state, Choice of yield function.

Non-Hardening & Elastic-Perfect Plasticity: Classical theories and its application to uniform & non uniform stress states, Hencky vs. Prandtl-Reuss, Elastic–Plastic Torsion and Bending of Beams, Thick walled cylinders.

Theory of the Slipline Field: Formulation of the Plane Strain Problem, Properties of Slipline Fields and Hodographs, Stress Discontinuities in Plane Strain, Construction of Slipline Fields and Hodographs, Analytical and Matrix Methods of Solution, Explicit Solutions for Direct Problems, Some Mixed Boundary-Value Problems, Superposition of Slipline Fields.

Limit Analysis: Collapse of Beams & Structures, Transverse loading of circular plates.

The Flow Curve: Uniaxial tests, Torsion tests, Compression tests, Bulge test, Equations to flow curve, Strain & work hardening hypothesis.

Plasticity with Hardening: Isotropic hardening, Non associated flow rules, Prandtl-Reuss flowtheory, Kinematic hardening.

Plastic Instability: Inelastic buckling of struts, Buckling of plates, Tensile instability, Circular bulge instability, Plate stretching.

Books Recommended

1. Theory of Plasticity: J. Chakrabarty.
2. Basic Engineering Plasticity: DWA Rees.

3. The Mathematical theory of plasticity: R.Hill.
4. Continuum Theory of Plasticity: S. Huang.
5. Fundamentals of the Theory of Plasticity: L.M. Kachanov.
6. Plasticity for Engineers: Theory and Applications: C. R. Calladine.
7. Plasticity: Fundamentals and applications, P. M. Dixit and U. S. Dixit
8. Nonlinear Solid Mechanics, D. Bigoni

ME-539	Theory of Plates and Shells	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to understand the theory, concepts, principles and governing equations of the theory of shells and plates
CO2	Possess the contemporary analytical, experimental and computational tools needed to solve the idealised problem
CO3	To perform critical analysis and design of typical shell structures
CO4	Be able to understand various methods for analyzing grids for roofs and bridges.

Small deflections of transversely loaded plates. Plates equations, boundary conditions. Rectangular and circular plates with different support conditions. General equations of elastic shells in invariant form. Membrane theory, Moment theory. Rotationally symmetric shells. Shallow shell theory. Examples.

Books Recommended

1. J.N. Reddy, "Theory And Analysis of Elastic Plates And Shells" Taylor & Francis 2006.
2. T Krauthammer, E Ventsel, "Thin Plates and Shells: Theory, Analysis, and Applications" Marcel Dekker Inc 2001.
3. S Timoshenko, "Theory of Plates and Shells" McGraw-Hill College 1959.

ME-540	Tribology	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding of the basic fundamentals of tribology and have a knowledge of surface topography and know how to model a rough engineering surface
CO2	Be familiar with the adhesion theories and effect of adhesion on friction
CO3	Be familiar with the different wear mechanisms and wear models
CO4	Have a knowledge of friction/lubrication mechanisms and know how to apply them to the practical engineering problem.

Introduction: Basics and Fundamentals of Tribology, Nature of Surfaces and their contact; physicomechanical properties of surface layer, Geometrical properties of surfaces, methods of studying surface, contact of smooth surface, contact of rough surfaces.

Friction: Role of friction, laws of static friction, Causes of friction, Adhesion theory, Laws of rolling friction, friction of metals and non-metals, friction measurement.

Wear: Definition of wear, mechanism of wear, Archard's Wear equation, factors affecting wear, wear measurement, wear of metals and non-metals.

Lubricants: Introduction, Types, Functions of lubricants: Types of lubricants and their industrial uses, Selection of lubricants, Properties and tests on lubricants, Analysis of used oils/lubricants, Particle counter, Spectroscopic Oil Analysis, Ferrography.

Lubrication Theories: Lubrication regimes, viscous flow and viscometry, Reynold's equation, hydrodynamic lubrication, hydrostatic lubrication, elasto-hydrodynamic lubrication, boundary lubrication, squeeze films, turbulent lubrication.

Books Recommended

1. Basic Lubrication Theory: Cameron
2. Fundamentals of Tribology: Bharat Bhushan
3. Fundamentals of Tribology: Basu, Sengupta, & Ahuja
4. Fundamentals of Fluid Film Lubrication: Hamrock, Schmid & Jacobson
5. Applied Tribology: Khonsari

ME-541	**Vibration Control**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To study the sources of mechanical vibration and influencing factors affecting level of vibration
CO2	To understand the fundamentals of vibration control
CO3	To learn the methods/techniques for vibration control by damping.

Factors affecting level of vibration, vibration reduction at the source, vibration control by structural design, selection of materials, vibration control by artificial damping, viscoelastic laminate, and material damping, vibration absorbers and auxiliary mass dampers, optimum, tunings and damping application of absorbers, Theory of vibration and shock isolation.

Books Recommended

1. Rao S S, "Mechanical Vibrations", Pearson Education, Delhi (2004).
2. Roger A A, "Fundamentals of Vibrations", Amerind Publisher Company Private Limited, New Delhi (1999).
3. Srinivas P, "Mechanical Vibration Analysis", Tata McGraw Hill Company Limited, New Delhi (1990).
4. Mallik A K, "Principles of Vibrations Control", Affiliated East West Press Private Limited, New Delhi (2000).
5. Lazan B J , "Damping of materials and members in structural mechanics" Pergamon Press 1968.

ME-542	**Vibro-Acoustics**	**(3 0 0 3)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Learn the basic concepts of noise and acoustics
CO2	Understand the radiation concept of single and multi-degree freedom systems. Learn the coupling of fluid-structure interaction
CO3	Understand the concept of sound radiation by various simple mechanical systems; Learn the basics of Finite element methods
CO4	Learn the basics of mechanical vibrations, modal analysis, and apply finite element method to determine the modal-model of simple structures.

Introduction to Engineering acoustics, wave approach to sound, noise measurement and instrumentation standards, sound pressure, power and intensity, noise radiation from vibrating bodies, single degree of freedom system (SDOF), multiple degree of freedom system (MDOF) vibration in longitudinal bars, fluid structure-acoustic interaction, airborne sound, quantification of sound, randomvibrations, flexural vibration of beams, plates and shells, sound sources, room acoustics, soundstructure, statistical energy analysis(SEA), Introduction about experimental modal analysis, finite element method approach to predict the mode shapes of a beam, plate or a three dimensional vibro-acoustic cavity.

Books Recommended

1. M. C. Junger, D. Feit, Sound, Structures and Their Interaction, The MIT Press (December 30, 1972).
2. F. J. Fahy, Sound and Structural Vibration: Radiation, Transmission and Response, cademic Press (January 28, 1987).
3. L. Cremer, M. Heckl, B.A.T. Petersson, Structure-Borne Sound: Structural Vibrations and Sound Radiation at Audio Frequencies, Springer, 3rd ed. edition (March 14, 2005).
4. R. H. Lyon, R. G. Dejong, Theory and Application of Statistical Energy Analysis, R.H. Lyon Corp (January 1, 1995).
5. R.H. Lyon, Machinery Noise and Diagnostics. Boston:Butterworths (1986)
6. E. Skudrzyk, Simple and Complex Vibratory Systems (Hardcover), Univ of Pennsylvania Press (June 1968).

ME-543	Viscoelasticity	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply knowledge of mathematics, science and engineering
CO2	To apply and integrate knowledge of viscoelastic behaviour to solve real life problems
CO3	Ability to learn the basics of viscoelasticity.

Viscoelastic Models & Hereditary Integrals: The basic elements: spring and dashpot, Maxwell fluid and Kelvin solid, Unit step function, Dirac function, Laplace transformation, Kelvin chains and Maxwell models, Creep compliance, relaxation modulus, Hereditary integrals, Integral equations.

Viscoelastic Beams: The correspondence principle, Hereditary integrals, Structures made of two materials, Solution of the integral equation, Differential equation of the beam, General correspondence principle, Beam on Continuous Support: Differential equation, A simple example, Concentrated load, Moving load on an infinite beam, Rolling friction.

Vibrations: Complex compliance, Dissipation, Application to specific materials, Relations between compliances, The simple spring-mass system, Forced vibrations.

Wave Propagation & Buckling of Columns: The differential equation, The wave front, Maxwell material, Viscous material, Oscillatory load, Bar with elastic restraint, The concept of stability, Inverted pendulum, Elastic column, Viscoelastic column

Viscoelasticity in Three Dimensions: Analysis of stress and strain, The viscoelastic law, Uni -axial stress, Viscoelastic cylinder in a rigid die, Correspondence principle, Two-dimensional problems, Thick-walled tube.

Books Recommended

1. Viscoelasticity by Wilhelm Flugge, Springer
2. Theory of Viscoelasticity by R. M. Christensen, Dover publications.

ME-544	Wave Propagation in Solids	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Be able to derive the governing equations for Navier’s equation of motion problems
CO2	Be able to analysis of stress wave in 1-D problem

CO3	To apply the basic stress wave equation in various boundary value problems
CO4	To solve half-space problems (Rayleigh waves).

Review of elasticity: Navier's equation of motion, Boundary and initial conditions.

Longitudinal and torsional waves: 1-D. D'Alembert's solution.

Method of characteristics: Radiation conditions; Wave packets; Group velocity.

Three-dimensional waves: Helmholtz decomposition, Dilatational and shear waves, Plane waves, Harmonic waves. Slowness diagrams.

Reflection and transmission: Reflection and transmission of P, SV, SH waves across interface; continuity conditions; Snell's law; Reflection and refraction at interfaces.

Half-space problems: Half-space problems: Rayleigh waves; Suddenly applied uniform normal pressure with zero body force; Cagniard de Hoop method; Buried load problem; Scattering from crack tips in mode III.

Waveguides:1-D waves; Dispersion; String on elastic foundation; Cut-off frequency; 2-d waves; Thin plates (Kirchhoff's theory); Lamb waves; Love waves; Rods; Pochammer-Chree equation.
Waves in anisotropic media and crystals

Experimental characterization: Kolsky bar

Advanced topics: One from: Plastic waves/Layered media/Visco-elastic waves/Shock waves/ Nonlinear waves/Thermal waves/Waves in discrete media/Scattering from mode I and II cracks.

Books Recommended

1. Achenbach J.D., Wave Propagation in Solids, Elsevier Science Publishers, 1975.
2. Graff K. F., Wave Motion in Elastic Solids, Dover Publications, 1991.
3. Brekhovskikh and GoncharovV., Mechanics of Continua and Wave Dynamics, L. Springer-Verlag, 1985.
4. MiklowitzJ., The Theory of Elastic Waves and Waveguides, North-Holland Publishing Company, 1978.

ME-545	Welding and Allied Processes	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding of the basic fundamentals of joining technology and have a knowledge of various joining processes
CO2	To attain the knowledge of different power sources used along with the VI characteristics
CO3	To understand the chemistry of fluxes, its reactions to the molten metal and various consumables used in welding/ joining technology
CO4	To attain the knowledge of various joining processes, their application, advantages and limitations.

Introduction: Introduction to joining technology, General survey and classification of welding processes, Safety and hazards in welding, Physics of the welding arc and arc characteristics, Metal transfer & its importance in arc welding, Various forces acting on a molten droplet and melting rates.

Power sources for arc welding: Power sources for arc welding, classification of power sources, characteristic curves.

Welding consumables: Fluxes, gases and filler materials for various welding processes.

Welding Processes and their Applications: SMAW, SAW, GTAW and related processes, GMAW and variants, PAW, Gas welding, Soldering, Brazing and diffusion bonding, Thermal cutting of metals, Surfacing and spraying of metals, Resistance welding processes: spot, seam, butt, flash, projection, percussion etc, Thermit welding, Electro-slag and electro-gas welding, Solid-state and radiant energy welding processes such as EBW; LBW; USW, Explosive welding; Friction weldingetc, Welding of plastics, Advances, challenges and bottlenecks in welding.

Books Recommended

1. Lancaster J F, “The Physics of Welding”, Pergamon Press (1984)
2. Little R F, “Welding and Welding Technology”, McGraw Hill Co (2001)
3. Nadkarni S V, “Modern Arc Welding Technology”, Ador Welding Ltd (2008)
4. Davies A C, “Welding”, Cambridge University press, (2005)

CURRICULUM

July 2022 admission onwards

APPROVED BY

BOARD OF STUDIES (BOS)

MEETING, July 19, 2022

M Tech in Thermal Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

Dr B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY,

JALANDHAR

Phone: 0181-2690301, 02 (Ext. 2101, 2104), Fax: 0181-2690932
Website: www.nitj.ac.in

Annexure-F

DR B R AMBEDKAR NATIONAL INSTITUTE OF TECHNOLOGY

JALANDHAR

Teaching Scheme and Syllabus
of
Regular M Tech in Thermal Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

SCHEME OF INSTRUCTION AND DETAILED SYLLABI

MASTER OF TECHNOLOGY IN THERMAL ENGINEERING

EFFECTIVE FROM JULY, 2022 ONWARDS

Course Scheme for M Tech in Thermal Engineering

FIRST SEMESTER				
S. No.	**Course No.**	**Subjects**	**L-T-P**	**Credit**
1.	MA-553	Computational Methods in Engineering	3-0-0	3
2.	ME-551	Advanced Thermodynamics	3-0-0	3
3.	ME-553	Advanced Heat Transfer	3-0-0	3
4.	ME-555	Computational Fluid Dynamics	3-0-0	3
5.	ME-XXX	Programme Elective-I	3-0-0	3
6.	ME-XXX	Programme Elective-II	3-0-0	3
7.	ME-561	Advanced Heat Transfer Lab	0-0-3	2
8.	ME-563	Computation and Simulation Lab	0-0-3	2
		Total	**18-0-6**	**22**

SECOND SEMESTER				
S. No.	**Course No.**	**Subjects**	**L-T-P**	**Credit**
1.	ME-552	Advanced Fluid Mechanics	3-0-0	3
2.	ME-554	Combustion and Emissions in IC Engine	3-0-0	3
3.	ME-556	Design and Optimization of Thermal Systems	3-0-0	3
4.	ME-558	Advanced Power Plant Cycles	3-0-0	3
5.	ME-XXX	Programme Elective-III	3-0-0	3
6.	ME-XXX	Programme Elective-IV	3-0-0	3
7.	ME-562	Thermal Comfort and Building Energy Simulation Lab	0-0-3	2
8.	ME-564	Engines and Unconventional Fuels Lab	0-0-3	2
		Total	**18-0-6**	**22**

THIRD SEMESTER				
S. No.	**Course No.**	**Subject**	**L-T-P**	**Credit**
1.	ME-600	Project Work for M Tech Dissertation, Part-I	0-0-12	6
2.	ME-601	Independent Study	0-0-6	3
		Total	**0-0-18**	**9**

FORTH SEMESTER				
S. No.	**Course No.**	**Subject**	**L-T-P**	**Credit**
1.	ME-600	Project Work for M Tech Dissertation, Part-II	0-0-24	12
		Total	**0-0-24**	**12**

Summary				
Semester	**I**	**II**	**III**	**IV**
Semester-wise total credit	**22**	**22**	**9**	**12**
Total credits	**65**			

Credit Distribution for M Tech in Thermal Engineering					
Category	**Sem - I**	**Sem - II**	**Sem - III**	**Sem - IV**	**Total No. of Credits to be earned**
Core Courses	**9**	**9**	**-**	**-**	**18**
Electives	**9**	**9**	**-**	**-**	**18**
Lab Courses	**4**	**4**	**-**	**-**	**8**
Seminar	**-**	**-**	**3**	**-**	**3**
Dissertation	**-**	**-**	**6**	**12**	**18**
Total	**22**	**22**	**9**	**12**	**65**

Programme Electives				
S. No.	**Course Code.**	**Subjects**	**L-T-P**	**Credit**
1	ME-565	Advanced IC Engines	3-0-0	**3**
2	ME-566	Advanced Power Plant Cycles	3-0-0	**3**
3	ME-567	Advanced Steam Power Plants	3-0-0	**3**
4	ME-568	Aerodynamics	3-0-0	**3**
5	ME-569	Alternative Fuels for IC Engines	3-0-0	**3**
6	ME-570	Applied Combustion	3-0-0	**3**
7	ME-571	Combustion Generated Pollution and Control	3-0-0	**3**
8	ME-572	Cryogenic Engineering	3-0-0	**3**
9	ME-573	Exergy Analysis of Thermal and Energy System	3-0-0	**3**
10	ME-574	Experimental Methods and Analysis	3-0-0	**3**
11	ME-575	Gas Dynamics	3-0-0	**3**
12	ME-576	Gas Turbines and Jet Propulsion	3-0-0	**3**
13	ME-577	Measurements in Thermal Engineering	3-0-0	**3**
14	ME-578	Microscale Transport Phenomena	3-0-0	**3**
16	ME-579	Multi-Phase Flow and Heat Transfer	3-0-0	**3**
17	ME-580	Optimization Theory	3-0-0	**3**
18	ME-581	Photovoltaic Cell and its Applications	3-0-0	**3**
19	ME-582	Refrigeration Systems and Components Design	3-0-0	**3**
20	ME-583	Renewable Energy	3-0-0	**3**
21	ME-584	Solar Passive Design and Sustainable Buildings	3-0-0	**3**
22	ME-585	Thermal Behaviour of Advanced Materials	3-0-0	**3**
23	ME-586	Turbomachinery	3-0-0	**3**
24	ME-587	Waste Heat Utilization and Polygeneration	3-0-0	**3**
25	ME-588	Science, Technology and Engineering Projects for Sustainability	3-0-0	**3**
26	ME-589	Solar Thermal Technologies	3-0-0	**3**

First Semester

MA-553	Computational Methods in Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the stepwise procedure to completely solve a fluid dynamics problem using computational methods
CO2	Ability to solve ODE problems using power series solutions
CO3	Ability to solve PDE using various analytical methods
CO4	Development of a clear understanding on Tensors, their operation and applications.

In relation to mechanical engineering applications, such as, heat transfer, fluid mechanics, vibrations, dynamics and others, the following topics will be covered:

Partial differential equations: Characteristics and classification of 2nd order PDEs. separation of variables special functions, Eigen function expansions, Fourier integrals and transforms, Laplace transforms, methods of characteristics, self-similarity.

Linear algebra: Matrix theory, solution of linear system of algebraic and differential equations; round-off errors, pivoting and ill-conditioned matrices. Eigenvalues and eigenvectors. Unitary, Hermitian and normal matrices.

Numerical Methods: Lagrange interpolation, splines, integration – trapezoid, Romberg, Gauss, adaptive quadrature. Explicity and implicity methods, multi-step methods, Runge-Kutta and predictor-corrector methods, boundary value problems, eigenvalue problems, systems of differential equations, stiffness. Accuracy, stability and convergence. Alternating direction implicity methods. Non-linear equations.

Books Recommended

1. Ames W F, “NumericalMethods for Partial Differential Equations”, 3rd Edition, Academic Press, New York (1992).
2. Dahlquist G and Björck A, “Numerical Methods”, Prentice-Hall, NJ (1974).
3. Jain M K, Iyengar S R K. and Jain R K, “Numerical Methods for Scientific and Engineering Computations”, 4th Edition New Age International (P) Limited, Publishers, New Delhi (2003).
4. Shampine L F, “Numerical Solution of Ordinary Differential Equations”, Chapman and Hall, New York (1994).
5. Kreyszig, E., "Advanced Engineering Mathematics", 8th Ed, John Wiley, Singapore, 2002.

ME-551	Advanced Thermodynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Ability to solve thermodynamics relations and obtain thermodynamic efficiency
CO2	Ability to analyze problems persisting with real and ideal gas
CO3	Ability to solve stability and phase relations
CO4	Understanding of the concept of reactive mixtures.

Recapitulation of fundamentals.The two laws of thermodynamics–Caratheodory‟s formulation, analysis of typical simple closed systems, analysis of open systems–exergy analysis.Multicomponent systems–concepts of fugacity, chemical potential.General conditions for thermodynamic equilibrium–

instability of thermodynamic equilibrium and phase transition.Thermodynamics of reactive mixtures.Elements of irreversible thermodynamics.

Books Recommended

1. Cengel& Boles, “Thermodynamics-An Engineering approach”.5th Ed, Tata McGraw Hill
2. Winterbone, Desmond E, “Advanced Thermodynamics for engineers”,1997, Elsevier
3. Annamalai, Puri, Ishwar.K. “Advanced Thermodynamics Engineering”2002, CRC Press.
4. Nag,P.K., “ Engineering Thermodynamics”,4th ed., Tata Mcgraw Hill.

ME-553	Advanced Heat Transfer	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand both the physics and the mathematical treatment of the advanced topics pertaining to the modes of heat transfer
CO2	Ability to formulate heat transfer conduction and radiation problems using ODE's and PDE's and obtain analytical solution
CO3	Apply principles of heat transfer to develop mathematical models for uniform and non-uniform fins
CO4	Analyze free and forced convection problems involving complex geometries with proper boundary conditions
CO5	Apply the concepts of radiation heat transfer for enclosure analysis.

Review of basic heat transfer, Introduction to Conduction, convection and radiation heat transfer, 1-D Steady State Heat Conduction, Fins with variable cross-section, generalized equation for fins, Fins of parabolic and triangular profiles, Transient in lumped systems, Multi-Dimensional Conduction, Analytical and numerical methods for solving multi-dimensional problems, Graphical method, Conduction shape factor, Analogical method, Relaxation Technique, Finite Difference method, Convective Heat Transfer, Momentum and Energy Integral Equation, Thermal and hydrodynamic boundary layer thickness, Heat transfer in a circular pipe in laminar flow when constant heat flux and constant wall temperature to the wall of the pipe, convection correlations for turbulent flow in tubes, Flow over cylinders and spheres, Flow across tube bundles/banks, Natural convection, Heat transfer from a vertical plate using the Integral method, Free convection in enclosed spaces, Mixed convection, Introduction to Boiling and Condensation Heat Transfer, Thermal radiation, Review of basics of surface radiation, non gray body, radiation shape factor, Hottel‟s Crossed String Method for finding shape factor, Radiosity and irradiation formulation, radiation shield and Gas radiation, Heat Exchangers, Review of basic concepts, Tubular and plate type heat exchanger, Overall heat transfer coefficient, LMTD, correction factor, Effectiveness, Introduction to design of heat exchangers.

Books Recommended

1. M.N. Ozisik, *Basic Heat Transfer*, Mc-Graw Hill, Inernational edition, 1988
2. J.P. Holman, *Heat Transfer*, McGraw Hill, 10th edition, 2010
3. F. Incropera, and D. J. Dewitt, *Introduction to Heat Transfer* –Wiley & Sons Inc., 6th edition,2010.
4. F. Kreith, *Principles of Heat Transfer*, Harper & Row, New York, 4th edition, 1986.
5. Gupta and Prakash, *Engineering Heat Transfer*, New chand& Bros, 4th edition
6. Bejan, *Convective Heat Transfer*, J. Wiley & Sons, 2nd edition, 1995.
7. S.P. Venkateshan, *Heat Transfer*, Ane Publication, 2009.
8. P.S.Ghoshdastidar, *Heat Transfer*, Oxford, Univ press, 2nd edition, 2012.
9. Domkundwar and Arora, *A Course in Heat and Mass Transfer*, DhanpatRai& Sons, 7th edition 2008.

ME-555	Computational Fluid Dynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand CFD as a tool, need for development and analysis in fluid dynamics and heat transfer problems
CO2	Handle ordinary and partial differential equations, and their linearization using CFD techniques
CO3	Understand basic concept of FVM and its implementation on heat transfer and fluid dynamics problems
CO4	Develop codes for various fluid dynamics and heat transfer problems based on CFD.

Review of basic fluid mechanics and the governing Navier-Stokes equations, Techniques for solution of PDEs – finite difference method, finite element method and finite volume method, Finite volume (FV) method in one dimension, Differencing schemes, Steady and unsteady calculations, Boundary conditions, FV discretization in two and three dimensions, Simple algorithm and flow field calculations, variants of SIMPLE, Turbulence and turbulence modeling, illustrative flow computations, Commercial softwares FLUENT and CFX – grid generation, flow prediction and post-processing.

Books Recommended

1. S V Patankar, *Numerical Heat Transfer and Fluid Flow*, McGraw Hill, NY, 2005.
2. John Anderson, "*Computational Fluid Dynamics*", McGraw-Hill Publication, First edition,1995
3. W M Kays and M E Crawford, *Convective Heat and Mass Transfer*, Mc-Graw Hill, New York 1993.
4. F M White, *Viscous Fluid Flow* by, Mc-Graw Hill, New York, 2nd Ed. 1991.
5. Robert Siegel and John Howell, *Thermal radiation Heat Transfer*, 4th Edition, Taylor and Francis NY, 2002.

ME-561	Advanced Heat Transfer Lab	(0 0 32)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand in utilizing the lab equipments for research purpose. Ability to conduct experiments and validate with the theoretical/analytical results
CO2	Understand heat transfer during charging and discharging of PCM in thermal energy storage system
CO3	Understand the flow patterns across different types of bodies using CCD camera. Understanding of thermal and hydrodynamic boundary layer for flow over surfaces
CO4	Understand the performance of different type of heat exchanger, spray cooling on a flat surface. Understanding of statistical analysis of the results.

<u>List of Experiments</u>

1. Evaluation of effect of surface roughness on heat transfer characteristics for absorber plate of solar flat plate collector. Perform statistical analysis of the results.
2. Evaluate the heat transfer characteristics for swirling flames impinging on the flat surface. Perform statistical analysis of the results.
3. Evaluate heat transfer during charging and discharging of PCM in thermal energy storage system.
4. Evaluate the thermal efficiency during charging, storing and discharging the PCM in thermal energy storage system and further evaluate the overall system thermal efficiency.
5. Evaluate the flow patterns across different types of streamline bodies and bluff bodies at different temperatures using CCD camera.
6. Evaluate the thermal and hydrodynamic boundary layer for flow over surfaces.

7. Evaluate the performance of shell and tube conventional and compact type heat exchanger.
8. Evaluate the performance of the spray cooling on a flat surface.

ME-563	Computation and Simulation Lab	(0 0 32)

Course Outcomes: At the end of the course the student will be able to:

CO1	Formulation and solution of problems in fluid flow and heat transfer
CO2	Understand the discretization of differential equations, provide boundary conditions and obtain numerical solution for fluid and heat transfer problems
CO3	Develop codes for numerical methods to solve 1D and 2D heat conduction and convection problems
CO4	Use commercial software like ANSYS, open foam etc. for solving real life engineering problems.

List of Experiments

1. To study 2D Laminar and turbulent flow problems using CFD codes/tools and validation with Blasius equation.
2. To study formation of flat plate boundary layer (2D) using CFD codes/tools and validation the results with analytical correlations.
3. To study the turbulent forced convection problem in a pipe using CFD codes/tools considering top and bottom walls as a constant wall temperature boundary condition and validation the results with Dittus-Boelter equation.
4. To study flow past a cylinder in steady state using CFD Code/tools.
5. To study flow past a cylinder in unsteady state using CFD Code/tools.
6. To study compressible Flow in a Nozzle using CFD Code/tools.
7. To study the free fall of droplet using CFD Code/tools and validate results with High speed camera images.
8. To study the rise of the bubble using CFD Code/tools and validate results with High speed camera images.
9. To study two phase flow in a microchannel with micro cavity using CFD Code/tools and validate results with High speed camera images.

Second Semester

ME-552	Advanced Fluid Mechanics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Ability to apply knowledge of fluid mechanics in research and technology
CO2	To enable the students to learn about the mathematical modeling techniques for fluid mechanics problems
CO3	To enable the students to understand the importance of analytical approximate solutions
CO4	Ability to understand and solve complex turbulent flow problems.

Review of basic laws of fluid flow in integral and differential form, kinematics, Ideal fluid flow. Newtonian fluid flow and applications, Creeping flow, Boundary layer theory, Transition and turbulence turbulent boundary layer Fundamentals of compressible flows Modelling and dimensional analysis.

Books Recommended

1. Douglas J F. Gasionckw, and Swaffield JP “Fluid Mechanics” 3rd edition AddisionWesley Longman, IncPitman, 1999.
2. Pao H F Richard “Fluid Mechanics” John Wiley and Sons. 1995
3. Kumar DS “Fluid Mechanics and Fluid Power Engineering” 6th edition SK KatariaandSons, Delhi. 1998.
4. Streeter V L and Wylie E B “Fluid Mechanics” McGraw Hill International.
5. Bansal R K “A text book of Fluid mechanics and Hydraulic Machines” 8th edition, LaxmiPublications Ltd. New Delhi, 2002.
6. Mohanty A K, “Fluid Mechanics”, 2nd Edition Prentice Hall of India Private Limited, NewDelhi, 2002.

ME-554	Combustion and Emissions in IC Engine	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To study the various properties of IC engine fuels and determination of air required for combustion
CO2	To study the various stages of combustion in SI and CI engines and understand the normal and abnormal combustion phenomena
CO3	To study the kinetics of CO, HC, NOx, their measurement and emission control strategies to conform to legislation standards
CO4	To study various alternative fuels for IC engines and their effect on performance and emission characteristics.

Fuels: Important qualities of SI and CI engine fuels and their ratings. Combustion of Fuels: Heating values of Fuels – SI engine fuels – CI engine fuels – Determination of minimum air required for combustion, conversion of volumetric analysis to mass analysis, Determination of air supplied from volumetric analysis of Dry flue gases,

Combustion in SI Engines: Stages of combustion, Flame front propagation– Factors influencing flame speed, Thermodynamic analysis: Burned and unburned mixture states. Analysis of cylinder pressure data, Combustion process characterization, Flame structure and speed; flame structure, laminar burning speeds, flame propagation relations, Cyclic variations in combustion, partial burning and misfire: definitions, causes of cycle – by – cycle and cylinder to cylinder variations, partial burning, misfire and engine stability. Spark Ignition: Ignition fundamentals, conventional ignition systems, alternative ignition systems, alternative ignition approaches, Abnormal Combustion: knock and surface ignition, knock fundamentals, fuel factors.

Combustion in CI Engines: Stages of combustion in CI Engine – Ignition delay – Factors effecting ignition delay, physical properties affecting delay, Types of diesel combustion systems: Direct injection systems, indirect injection systems, Analysis of cylinder pressure data; combustion efficiency, DI engines, IDI engines, Fuel spray behavior: Fuel injection, overall spray structure, atomization, spray penetration, droplet size distribution and spray evaporation, Ignition delay: definitions and discussion, fuel ignition quality, auto ignition fundamentals, effect of fuel properties.

Emission and Control: Emission of various pollutants from the engine, Kinetics of NOx, HC and CO formation in SI and CI Engines, Measurement of Emissions, Exhaust gas treatment. Emission Standards

Alternative Fuels – Alcohols - CNG – LPG – Hydrogen - Biodiesels – Biogas - Dual fuel operation. Performance and Emission Characteristics of SI and CI Engines using these alternatefuels.

Books Recommended

1. John. B.Heywood, *Internal Combustion Engine Fundamentals*, McGraw Hill, 1988.
2. E.F. Obert, *Internal Combustion Engine and Air Pollution*, Harper and Row Publishers, 1973.
3. V.L. Maleeve, *Internal Combustion Engines*, McGraw Hill Book Company, 1945.
4. Colin R.Ferguson and Allan T.Kirkpatrick, *Internal Combustion Engines*, Wiley publishers, 2000.
5. Mathur& Sharma, *Internal Combustion Engines*, Dhanpatrai Publishers. 2006.
6. V.Ganesan, *Internal Combustion Engines*, Tata McGraw Hill, 2003.
7. H.N.Gupta, *Fundamentals of Internal Combustion Engines*, PHI, New Delhi, 2006.
8. PulkRabek W W, *"Engineering Fundamentals of Internal Combustion Engine"*, Pearson EducationNew Delhi (2003).

ME-556	Design and Optimization of Thermal Systems	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the various Thermal systems encountered in Engineering along with the importance of their associated parameters
CO2	To apply the various concepts learnt in the subjects of Thermodynamics, Fluid Mechanics, Heat Transfer and Applied Mathematics to predict and simulate the performance of Thermal systems
CO3	To understand the different Optimization techniques and develop the skills to Model and analyze the various Thermal systems
CO4	To develop skills to solve single as well as Multivariable optimization problems.

Introduction to Design and Analysis, and Project Initiation, Review of Fluid Mechanics, Thermodynamics & Heat transfer, System identification and description & component design: Heat exchangers, Prime movers, System Design and Optimization Techniques and Economic Evaluation, Engineering economics.

Books Recommended

1. Stoecker, W., Design of Thermal Systems, McGraw-Hill
2. Burmeister, L.C., Elements of Thermal-Fluid System Design, 1998, Prentice Hall
3. Jaluria, Y., Design and Optimisation of Thermal Systems, 2007, McGraw-Hill,
4. Janna, W.S., Design of Fluid Thermal Systems, 1993, PWS-Kent Publishing, 1993.

ME-558	Advanced Power Plant Cycles	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To acquire the knowledge on advanced power plant cycles such as combined cycle, Kalina cycle, zero emission cycle (hydrogen-oxygen cycle), nuclear cycle etc
CO2	To estimate irreversibilities of the power plant components for exergy analysis
CO3	To simulate and optimize the real cycles
CO4	To analyse the power plant at off-design conditions
CO5	To distinguish between various power generation units and choose one that meets desired economic, environmental and social requirements.

Review of various ideal cycles–Rankine and Brayton–and fuel-air cycles. Thermodynamics optimization of design parameters. Real cycle effects–internal and external irreversibilitites, pressure drops, heat loss, condenser air leakage, fouling of heat transfer surfaces, combustion losses–and their impact on the thermodynamic cycle. Optimization of real and double reheat cycles. Analysis of off-design performance. Combined cycles–ideal and real cycles–thermodynamic analysis. Design of alternate schemes for combined cycles– single, dual and triple pressure cycles, and their optimization. Retrofit of ageing power plants. Parametric analysis–effects of gas and steam cycle variables. Binary vapour and Kalinacycles. Thermochemical and H2-O2 cycles. Cycles for nuclear power plants (PWR, BWR, PHWR, FBR). All simulations will involve extensive use of numerical techniques as part of laboratory work.

Books Recommended

1. Wiesman J and Eckart R, “Modern Power Plant Engineering”, Prentice Hall,New Delhi ,1985.
2. Nag P K, “Power Plant Engineering”, Tata McGraw Hill,New Delhi ,1998.
3. Kostyuk.A and Frolov V, “Steam and Gas Turbines”, Mir Publishers, Moscow ,1988.
4. Aschner F S, “Planning Fundamentals of Thermal Power Plants”, John Wiley ,1978.
5. Eastop T D and McConkey, “Applied Thermodynamics”, Longman Scientific and Technical, 1986.

ME-562	**Thermal Comfort and Building Energy Simulation Lab**	**(0 0 3 2)**

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the basic principles and fundamentals of mechanical engineering systems in the building engineering science
CO2	To understand basic principle of engineering to design and analyze various types of mechanical systems in built environment
CO3	To provide a bird eye view and holistic approach of modeling and simulation of mechanical systems for energy efficiency and sustainable development.

<u>List of Experiments</u>

1. PV Solar systems modeling and analysis
2. Introduction to building energy simulation tools i.e. e-Quest, Energy plus, TRNSYS
3. Modeling techniques, validation of simulation model
4. Simulation for energy efficiency of buildings
5. Simulation for ECBC code compliance by whole simulation method

ME-564	**Engines and Unconventional Fuels Lab**	**(0 0 3 2)**

Course Outcomes: At the end of the course the student will be able to:

CO1	To make the students understand the functioning of various sensors and actuators in an Engine
CO2	To make students understand the effect of EGR on NOx emissions
CO3	To make the students understand the effect of various engine parameters on performance and combustion characteristics
CO4	To enable the students understand the determination of Uncertainty in measurements.

<u>List of Experiments</u>

1. To measure the properties of the fuel
   a. Acid Number
   b. Viscosity of oils/ liquid fuels
   c. Density and specific gravity of oils/ liquid fuels
2. Study of Performance characteristics of a Single Cylinder DI engine and its comparison with similar CRDI engine
3. Study of Various sensors and actuators required for an open ECU based CRDI engine.
4. Study of Performance and combustion characteristics of multicylinder CRDI engine.
5. Utilization of Exhaust Gas Recirculation (EGR) for reduction of NOx emissions in compression ignition engine.
6. To perform an Uncertainty analysis on engine performance and combustion parameters.

Programme Electives

ME-565	Advanced IC Engines	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To expose the students to various air standard and fuel air cycles and the reasons for the deviation of real cycles from ideal cycles
CO2	To enable the students to do the performance analysis of IC Engine and justify the suitability of IC Engine for different applications
CO3	To study the new trends in engines with an aim to improve the performance and emission characteristics
CO4	To study the recent trends in Engine Management System

Cycle Analysis: Otto, diesel, dual, Sterling and Brayton cycles, comparison of air standard, fuel air and actual cycles, simple problems on the above topics.

Measurement and Testing: Measurement of IP. FP, BP, friction fuel consumption, air consumption, speed, emission. Performance Characteristics of SI and CI Engines, Engine performance maps, Heat Balance sheet.

Special Types of Engines: Introduction to working of stratified charged engines, Wankel engine, variable compression engine, Surface ignition engines, free piston engines, Current engines and future trends (e.g. Convergence of SI and CI engine technology, Control developments, fuel quality), Effect of air cleaners and silencers on engine performance.

Recent Trends: Homogeneous Charge Compression Ignition Engine, Lean Burn Engine, Stratified Charge Engine, Surface Ignition Engine, Four Valve and Overhead cam Engines, Electronic Engine Management, Common Rail Direct Injection Diesel Engine, Gasoline Direct Injection Engine, Data Acquisition System –pressure pick up, charge amplifier PC for Combustion and Heat release analysis in Engines.

Electronic Engine Management: Computer control of SI & CI engines for better performance and low emissions, closed loop control of engine parameters of fuel injection and ignition

Books Recommended

1. Heinz Heisler, „Advanced Engine Technology," SAE International Publications, USA,1998 Ganesan V. "Internal Combustion Engines", Third Edition, Tata Mcgraw-Hill ,2007
2. Tom Denton. "Automobile Electrical and Electronic Systems", Elsevier, 2004
3. John B Heywood," Internal Combustion Engine Fundamentals", Tata McGraw-Hill, 1988
4. Richard Stone. "Introduction to Internal Combustion Engine", Society of Automotive Engineers Inc 1999
5. Hua Zhao, NicosLadommatos. "Engine combustion instrumentation and diagnostics", Society of Automotive Engineers, 2001
6. Robert Bosch GmbH."Bosch Automotive Electrics and Automotive Electronics: Systems and Components, Networking and Hybrid Drive", Springer View.

ME-566	Heat Exchangers	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To introduce basic heat transfer mechanisms in heat exchangers; Classification of Heat Exchangers

CO2	To understand and apply the different heat transfer and pressure drop correlations for single and two phase flows
CO3	To understand the concepts related to Thermal and Hydraulic designs of heat exchangers and perform calculations for the design of Double pipe, Shell and Tube and compact Heat Exchangers
CO4	To understand the concepts of Fouling and its impact on thermal design of heat Exchangers
CO5	To introduce the various commercial soft wares available to design the various types of Heat Exchangers.

Applications. Basic design methodologies – LMTD and effectiveness-NTU methods. Overall heat transfer coefficient, fouling. Correlations for heat transfer coefficient and friction factor. Classification and types of heat exchangers and construction details. Design and rating of double pipe heat exchangers, compact heat exchangers, plate and heat pipe type, condensers, cooling towers. Heat exchanger standards and testing, Heat transfer enhancement and efficient surfaces. Use of commercial software packages for design and analysis, optimization.

Books Recommended

1. Kays and London, "Compact Heat Exchangers", McGraw Hill.
2. Hesselgreaves, "Compact Heat Exchangers Selection, Design & Operation", Pergamon.
3. Shah, R.K. &Sekulic D.P, "Fundamentals of Heat Exchanger Design", John Wiley & Sons.
4. Kakac& Liu, "Heat Exchangers-Selection, Rating and Thermal Design", 2nd ed., CRC Press

ME-567	Advanced Steam Power Plants	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply the knowledge of advanced thermal power plants from simple cycle to supercritical cycle
CO2	To design the components in thermal power plants and cogeneration plants such as boiler, condenser and other heat exchangers
CO3	To conduct the energy auditing and exergy evaluation
CO4	To analyse latest power augmentation techniques in thermal power plants
CO5	To know about the kind of boilers being used in various industries and their applicability.

Thermal Power Plant Engineering, Energy sources and scenario – Power Plant Cycles – Reheat – Regenerative, Supercritical -Coupled and combined – Cogeneration Plants, Exergy analysis of power plant cycles, Coal, its properties, combustion, Analysis and sizing of Power Plant Components: Steam generator, Condenser, Cooling tower and other heat exchangers, Power plant economics, energy audit. Recent trends in power production.

Books Recommended

1. R.W. Haywood, *Analysis of Engineering Cycles*, Pergamon Press, 1975.
2. A.W. Culp, *Principles of Energy Conversion*, McGraw Hill, 1979.
3. M.M. Elwakil, *Power Plant Technology*, McGraw Hill, 1984.
4. T.D. Eastop and A.McConkey, *Applied Thermodynamics*, ELBS, 1986.
5. P.K.Nag, *Power Plant Engineering*, Tata McGraw Hill, 2000.
6. J.Weisman, and R.Eckart, *Modern Power Plant Engineering*, Prentice Hall, 1985.

ME-568	Aerodynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To develop knowledge in the field of potential flow theory and their applications in aerodynamics problems
CO2	To develop ability to model lift for flow over arbitrary cylinders
CO3	Understanding to model lift over airfoil using thin airfoil theory and Kutta-Jowkowski law
CO4	Understanding of laminar and turbulent boundary layer theory.

Aerodynamic forces and moments; continuity, momentum and energy equations; Inviscid incompressible flow – incompressible flow in a low speed wind tunnel, source and doublet flows, nonlifting flow over a circular cylinder, Kutta-Joukowski theorem; Incompressible flow over airfoils and finite wings – Kutta condition, Kelvin‟s circulation theorem, Biot-Savart law, Helmholtz vortex theorem, Prandtl‟s classical lifting line theory; Thin aerofoil theory; Three dimensional source and doublet; Inviscid compressible flow – normal and oblique shocks, expansion waves, supersonic wind tunnels; Elements of hypersonic flow, Newtonian theory; Equations of viscous flow; Laminar and turbulent boundary layers; Panel methods in aerodynamics.

Books Recommended

1. J.D. Jr.Anderson, *Fundamentals of Aerodynamics*, McGraw Hill
2. J.J. Bertin, *Aerodynamics for Engineers*, Pearson Education, 2002.
3. E.L. Houghton and N.B. Carruthers, *Aerodynamics for Engg. Students*, Arnold Pub., 1988.
4. A.M. Kuethe, and C.Y. Chow, *Foundations of Aerodynamics*, Wiley, 1998.
5. L.J. Clancy, *Aerodynamics*, Himalayan Books, 1996.

ME-569	Alternative Fuels for IC Engines	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Interpret and distinguish between the different types of conventional and non-conventional fuels
CO2	Demonstrate the utilization of synthetic and substitute fuels for practical applications
CO3	Describe various parameters that are utilized to characterize alternative fuels and its combustion process
CO4	Solve renewable energy related problems with knowledge in fossil fuels and alternative fuels
CO5	Demonstrate knowledge in production methods of different alternative fuels
CO6	Select from different alternative fuels available for specific potential applications
CO7	Understand the socio-economic, environmental impacts, limitations and applications of alternative fuels.

Hydrocarbon fuels: Crude petroleum oil and its refining, products of refining, availability of hydrocarbon fuels and their impact on environment.

Gasoline: Chemical composition, combustion characteristics of gasoline, Effect of various engine parameters on the combustion of gasoline; Knocking, Octane number, Effect of sulphur, ash forming additives, oxygenates, olefins, aromatics, benzene content.

Diesel: Chemical composition, combustion characteristics of diesel, Engine parameters affecting the combustion of diesel; Cetane number, sulphur content, density, volatility, distillation characteristics.
Ethanol and Methanol: Benefits of using ethanol, methanol as fuel, their method of production, properties of ethanol, methanol, methods of using ethanol, methanol in diesel engines: Fumigation, solutions, Spark injection, dual injection, ignition improvers, surface ignition, low heat rejection.

Biodiesel: Definition, advantages of biodiesels, methods of producing biodiesels; blending, cracking, Transesterification, super critical methanol Transesterification, properties of biodiesels, emission characteristics of biodiesels.

Gaseous Fuels: LPG, LNG and CNG Composition, combustion characteristics, dispensing methods, emission studies. Hydrogen, its combustion characteristics, flashback control technique, safety aspects and system development. Biogas, producer gas, their method of preparation, their use as an enginefuel.

Books Recommended

1. Biodiesel, Basics And Beyond New Society Pub 2006
2. McGowan, Thomas Biomass and Alternate Fuel Systems: An Engineering and Economic Guide Wiley-AIChE 2009
3. Processing and Testing of Biodiesel Fuels Serials Publications 2009.

ME-570	Applied Combustion	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To enable the students to understand the fundamentals of combustion and different modes of burning
CO2	To understand the working of various combustion devices and their complicacies involved
CO3	To understand the key features required for developing technologies based on combustion process
CO4	To make students understand the future avenues in combustion technology.

Review of combustion fundamentals. Gas-fired furnace combustion. Oil-fired furnace combustion. Gas turbine spray combustion. Combustion of solids. Industrial applications involving combustion. Burner design, testing and control. Emissions. Combustion safety.

Books Recommended

1. Kenneth Kuan-yunKuo, Principals of Combustion, John Wiley and Sons, NY (2005).
2. Stephen R. Turns, An Introduction to Combustion: Concepts and Applications, 2nd Edition, Mc-Graw Hill, (2005).
3. Norbert Peters, Turbulent Combustion, Cambridge University Press, First Ed. (2000).

ME-571	Combustion Generated Pollution and Control	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the fundamental knowledge of thermodynamics and chemical kinetics of combustion
CO2	Apply the general principles of combustion of fuels
CO3	Explain the formation mechanisms of combustion-generated air pollutants
CO4	Understand and select appropriate methods for air pollution measurement and control
CO5	Determine the air pollutant concentration and dispersion from sources.

Generation and nature of pollutants from various combustion sources, their effects on health and the environment. Emissionindices. Thermo-chemistry of pollutant formation, stoichiometry, chemical thermodynamics, kinetics. Pollutants from I.C. engines, power plants, domestic and other sources. Meteorology and dispersion of pollutants, instruments for pollutant measurement and monitoring. Legislation and emission standards.

Books Recommended

1. Edward f. Obert, Internal Combustion Engine and air pollution, Intent Education publishers.
2. John B.Heywood, Internal Combuston Engine Fundamentals, McGraw Hill Book, 1988.
3. Crouse William, Automotive Emission Control, Gragg Division/McGraw Hill, 1980.
4. Ernst S.Starkman, Combustion Generated air pollution, Plenum Press.
5. George Springer and Donald J.Patterson, Engine Emissions, Pollutant formation and measurement, Plenum press.
6. Obert.E F, IC Engines and air pollution, Intent Education publishers.

ME-572	Cryogenic Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the various thermodynamics cycles used for cryogenics
CO2	To understand the practical applications of cryogenics in space, rocket, biotechnical applications
CO3	To develop understanding in the storage of working fluid used for cryogenics
CO4	To develop skill for the understanding of the type and phase of working fluid used for cryogenics.

Cryogenic Systems, Introduction, Insight on Cryogenics, Properties of Cryogenic fluids, Material properties at Cryogenic Temperatures, Carnot Liquefaction Cycle, F.O.M. and Yield of Liquefaction Cycles. Inversion Curve - Joule Thomson Effect, Liquefaction Cycles, LindeHampson Cycle, Precooled LindeHampson Cycle, Claudes Cycle, Dual Cycle, Helium Refrigerated Hydrogen Liquefaction Systems. Crtical components in Liquefaction Systems, Cryogenic Refrigerators: J.T.Cryocoolers, Stirling Cycle Refrigerators, G.M.Cryocoolers, Pulse Tube Refrigerators, Regenerators used in Cryogenic Refrigerators, Magnetic Refrigerators, Applications: Applications of Cryogenics in Space Programmes, Superconductivity, Cryo Metallurgy, Medical applications, Cryogenic heat transfer: applications, Material Properties at cryogenic temperatures, specific heats and thermal conductivity of solid, liquid and gases, Cryogenic insulations, gas-filled and evacuated powders and fibrous materials, microsphere and multi-layer insulations.

Books Recommended

1. R.B. Scott, *Cryogenic Engineering*, Van Nostrand and Co., 1962
2. Herald Weinstock, *Cryogenic Technology*, 1969
3. Robert W.Vance, *Cryogenic Technology*, Johnwiley& Sons, Inc., New York, London,
4. Klaus D.Timmerhaus and Thomas M.Flynn, *Cryogenic Process Engineering, Plenum Press*, 1989
5. Randall F.Barron, *Cryogenic Systems*, McGraw Hill, 1985.

ME-573	Exergy Analysis of Thermal and Energy System	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To enable the students to understand the exergy method of energy systems
CO2	To develop the knowledge of students in applying the exergy approach to solve the problems of thermal power plants
CO3	Design the thermal and energy systems with exergy approach
CO4	Do the exergetic analysis to find the bottlenecks in the process/component. Identify the drawbacks and recommend the modifications.

Concept of exergy – Available work – Exergy loss, Reversibility and irreversibility – exergy for control region – physical exergy and chemical exergy – closed system analysis – Exergy evaluation of solid, liquid and gaseous fuels – tables and charts.

Thermodynamic Properties: Combined first and second law equation-Maxwell relations -

Clapeyron equation – internal energy, enthalpy, entropy, exergy – specific heats as a function of temperature and pressure.

Thermodynamic Equilibrium: Combustion – Combustion reactions - Enthalpy of formation - Entropy of formation - Reference levels for tables - Heat of reaction - Adiabatic flame temperature – General product – Enthalpies – Equilibrium – Chemical equilibrium of ideal gases – Effects of Non-reacting gases– Equilibrium in multiple reactions – The vont Hoff Equation – The chemical potential and phase equilibrium – The Gibbs Phase Rule.

Numerical methods: Use of numerical methods to solve the exergy problems with iterations.

Exergy Applied to Processes: Expansion process - compression process – heat transfer processes – mixing and separation processes – chemical process and combustion – Linde air liquefaction plant – CHP plant – GT-ST combined cycle plant – refrigeration plant – heat pump systems – fuel cell systems.

Thermoeconomic Applications of Exergy: Structural coefficients exergy losses – optimization of component geometry – thermoeconomic optimization of thermal systems – thermoeconomic optimization of heat exchanger in a CHP plant – exergy costing in multi product plant.

Books Recommended

1. Dinçer, Marc A. Rosen, 2007, Exergy: Energy, Environment, and Sustainable Development, Elsevier.
2. Lucien Borel, Daniel Favrat, Thermodynamics and Energy Systems Analysis: From Energy to Exergy (Engineering Sciences-Mechanical Engineering), 2010 EPFL Press.
3. Valero A., C. C., 2009, "Thermoeconomic Analysis," Encyclopedia of Life Support Systems,Vol. Exergy, Energy System Analysis, and Optimization, Oxford, United Kingdom: EOLSS Publishers.
4. KalyanAnnamalai, Ishwar K. Puri, Milind A. Jog, 2011, Advanced Thermodynamics Engineering, Second Edition (Computational Mechanics and Applied Analysis), CRC Press.
5. Aloui, Fethi, and Ibrahim Dincer, eds. 2018. Exergy for A Better Environment and Improved Sustainability, Volume 1, Series title: Green Energy, Technology, Springer, Cham.

ME-574	Experimental Methods and Analysis	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the importance of doing experiments in investigation of physical systems
CO2	To understand the importance of experimental data and its analysis
CO3	To understand various techniques and their selection for experimental investigations.

Statistics: Distributions, estimators, confidence levels, sample size, test of hypothesis, goodnessof- fit test Chauvenet‟s criteria; Regression analysis, co-relations. Uncertainty analysis. Design of experiments.

Instruments: Specifications. Static and dynamic characteristics. Instruments for measuring distance, profile, pressure, temperature, velocity, flow rate, level, speed, force, torque, noise, chemical analyses. Estimation of systematic errors. Signal conditioning, data acquisition and analysis. Transducers, A-D & D-A converters, interfacing with computers and PLCs.

Control theory fundamentals: Steady state and transient response, Stability analysis Routh and Nyquist criteria, Root locus method. Sequence and programmable logic controllers. Hydraulic, pneumatic and electrical systems.

Laboratory: Calibration. Experiments related to heat transfer, fluid mechanics, thermodynamics and gas dynamics. Project on experiment design including drawings, wiring diagrams, selection of instruments and computer interfacing. Use of various controllers and actuators. Data management and presentation.

Books Recommended

1. Dally J E and Rilley W P, "Experimental Stress Analysis", 3rd Edition, McGraw Hill, New Delhi (1991).
2. Dove R C and Adams P H, "Experimental Stress Analysis and Motion Measurement", McGraw Hill, New York (1978).
3. Holister C S, "Experimental Stress Analysis", 5th Edition, Cambridge University Press (1987).
4. Dally J E and Rilley W P, "Introduction to Photomechanics", Prentice Hall Inc, NJ (1981).
5. Mubeen A, "Experimental Stress Analysis", 1st Edition DhanpatRai and Sons, New Delhi (1997).

ME-575	Gas Dynamics	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the concept of different types of shocks and waves: normal and oblique, compression and expansion waves
CO2	To understand the compressible flow behavior with friction and heat transfer
CO3	To understand applications in measurement of subsonic and supersonic flows, wind tunnels, medical, aircraft and rocket propulsion
CO4	To provide introduction hydraulic turbines and pumps.

Recapitulation of fundamentals, introduction to numerical analysis of compressible flow. Oblique shocks, compression and expansion waves, Prandtl Meyer expansion. Interaction of shock waves and shock-boundary layer interaction. Flow with friction and heat transfer. Introduction to 1-D transient and 2-D compressible flow. Method of characteristics. Applications in measurement of subsonic and supersonic flows, wind tunnels, medical, aircraft and rocket propulsion. Introduction to hypersonic, high temperature flows and astro gas dynamics.fans.Surge, stall.Hydraulic turbines and pumps.

Books Recommended

1. Shepherd D G, "An Introduction to Gas Turbine", Von Nastrand, New York (1949).
2. Stodola A, "Steam and Gas Turbines", McGraw Hill Book Company, (1970).
3. Shapiro A M, "Dynamics and Thermodynamics of Compressible Fluids", Ronald"s Press, New York (1953).
4. Benson R W, "Advanced Engineering Thermodynamics", Pergamon Press, London (1975).
5. Cohen H, Rogers G F C and Saravanamuttoo H I H, "Gas Turbine Theory", Orient Longman Limited, New Delhi (1996).

ME-576	Gas Turbines and Jet Propulsion	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the applications of turbines and jet propulsion and their energy requirements
CO2	To understand the various thermodynamics cycles used for cryogenics
CO3	To understand the concept of performance and combustion
CO4	Understand the principles of jet propulsion. Types of aircraft engines.

Introduction, Centrifugal fans Blowers and Compressors, Brayton cycle, regeneration and reheating cycle analysis., Axial flow fans and compressors, Elementary theory, degree of reaction, three dimensional flow, simple design methods, blade design, calculation of stage performance, overall performance and compressibility effects. Performance characteristics.

Axial flow turbines: elementary theory, vortex theory, choice of blade profile, pitch and chord estimation of stage performance, he cooled turbine, Combustion system: Form of combustion, important factors affecting combustion chamber design, combustion processes, combustion chamber performance, practical problem., Simple gas turbines: Components, characteristic, pressure losses, methods of improving part load performance, behaviour of gas turbines, Gas turbine rotors and stresses, Jet Propulsion -introduction - Early aircraft engines -Types of aircraft engines - Reciprocating internal combustion engines - Gas turbine engines - Turbo jet engine - Turbo fan engine - Turbo-prop engine. Aircraft propulsion theory: thrust, thrust power, propulsive and overall efficiencies.

Books Recommended

1. Cohen and Rogers, *Gas Turbines Theory*, Wesley Longman, 1996.
2. J.F. Lee, *Theory and design of stream and gas turbine*, McGraw Hill, 1954.
3. V. Ganesan, *Gas Turbine*, Tata McGraw Hill, 3rd edition, 2010.
4. R. Yadav, *Steam & Gas Turbines and Power Plant Engineering*, Central Publishing House, 2004.

ME-577	Measurements in Thermal Engineering	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the concepts of errors in measurements, statistical analysis of data, regression analysis, correlation and estimation of uncertainty
CO2	Describe the working principles in the measurement of field and derived quantities
CO3	Analyze sensing requirements for measurement of thermo-physical properties, radiation properties of surfaces, and vibration
CO4	Understand conceptual development of zero, first and second order systems. Interpret International Standards of measurements (ITS-90) and identify internationally accepted measuring standards for measurands.

Basic concepts of measurements, Different types of errors in measurements, Statistics in Measurements, Principle of least square in measurements, Standard deviation, variance, Uncertainty in measurements, Influence coefficients, Linear regression, Least square fit, Goodness of fit, Correlation coefficient, Index of correlation, Error band, Multiple linear regression, Parity plot, Temperature measurements (Thermometry): Fundamental process of measurements, Thermometric thermometer(thermocouples), Thermoelectricity, Seebeck effect, Peltier effect, Thomson effect, Laws of Thermoelectric circuits, Common thermocouple pairs used in practice, Thermocouple junction in series, Measurement of temperature of a moving fluid using a thermo well, Temperature measurement in the solid, Measurement of Transient temperature, Resistance Thermometer, Measurements of temperature in Thermal radiation, Spectroscopic determination of gas temperature. Measurements of Heat Flux, Interferometry, Differential Interferometer, Pressure Measurements: Different pressure measurements, Vacuum measurements, Pirani gauge, Ionization gauge, Dynamic response of a U-tube manometer. Flow and velocity Measurements, Different methods of incompressible and compressible flow measurements, Pitot static tube, Hot wire anemometer, Ultrasonic method, Doppler effect, Vortex Shedding Flow meter, Laser Doppler velocity meter.Viscosity Measurement: Capillary method, Torque method, Saybolt viscometer, Pollution monitoring, Gas chromatography, NDIR analyzer.

Books Recommended

1. J.P.Holman, Experimental Methods for Engineers, McGraw Hill, 2001.
2. S.P.Venkateshan , *Measurements in Thermal Engineering*, Ane Books Pvt.Ltd.,
3. S.M.Yahaya, *Compressible Flow*, New Age International(p) Ltd., 2nd edition, 1998.

ME-578	Microscale Transport Phenomena	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding of the fundamentals of microscale fluid and heattransfer phenomena;
CO2	Understanding of dominant forces and their effects in microscale devices and systems

CO3	Understanding of the differences between the macro-and microscale fluid flows and heat transfer phenomena
CO4	Understanding of various microfluidic applications; and to explore new possible microfluidic applications in the numerous emerging fields.

Introduction: Origin, Definition, Benefits, Challenges, Commercial Activities, Physics of Miniaturization, Scaling Laws. Hydraulic Resistance and Circuit Analysis, Straight Channel of Different Cross-Sections, Channels in Series and Parallel.

Single-Phase Liquid Flow: Micro-Scale Fluid Mechanics: Intermolecular Forces, States of Matter, Continuum Assumption, Governing Equations, Constitutive Relations, Pressure Driven Liquid Micro-flow, Physics of Near-Wall Microscale Liquid Flows, Low *Re* Flows, Entrance Effects. Exact Solutions, Couette Flow, Poiseuille Flow, Stokes Drag on a Sphere, Time Dependent Flows.

Microscale Heat Conduction: Energy Carriers, Time and Length Scales, Scale Effects, Fourier's Law, Scale Effects of Thermal Conductivity.

Microscale Convection: Scaling laws, Temperature jump boundary condition, Convection in parallel plate channel flow and Couette Flow With and Without Viscous Dissipation, Heat Transfer in Micro Poiseuille Flows, Similarity and Dimensionless Parameters, Flow Boiling in Micro Channels, Nucleate and Convective Boiling, Saturated and Sub-Cooled Flow Boiling, Condensation Heat Transfer in Micro Channels, Micro Heat Pipes.

Single-Phase Gas Flow: Boundary Conditions, Wall Slip Effects and Accommodation Coefficients, Flow Analysis of MicroscaleCouette Flows, Pressure Driven Gas Micro-Flows with Wall Slip Effects, Effects of Compressibility, Introductory Concepts on Gas Flows in Transitional and Free Molecular Regimes.

Some Representative Applications of Micro-Scale Flows: Micro-Propulsion and Micro Nozzles, Micro-pumps, Micro-valves, Micro-flow sensors and Accelerometers, Micromixers, Micro-particle separators, Micro-reactors.

Books Recommended

1. P. Tabeling, Introduction to Microfluidics, Oxford University Press, 2005.
2. G. Karniadakis, A. Beskok, N. AluruMicroflows&Nanoflows: Fundamental andSimulation, Springer Publication, 2005.
3. J. Berthier and P. Silberzan, Microfluidics for Biotechnology, Artech House, 2006.
4. H. Bruus, Theoretical Microfluidics, Oxford University Press, 2008.

ME-579	Multi-Phase Flow and Heat Transfer	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand concept of multi phase flow and general governing equations
CO2	Understand physics involved in complex multiphase fluid flows
CO3	Analyse heat transfer and fluid dynamics involved in Pool and boiling
CO4	Evaluate film and dropwise condensation.

Introduction: Review of 1-D conservation equations in single phase flows; Governing equations for homogeneous, separated and drift-flux models.

Flow pattern maps: Horizontal and vertical systems; Simplified treatment of stratified, bubbly, slug and annular flows.

Pool Boiling: Thermodynamics of Pool boiling- onset of nucleation, heat transfer coefficients, critical heat flux, effect of sub-cooling.

Flow boiling: onset of nucleation, heat transfer coefficients, critical heat flux, effect of sub-cooling. Condensation- Film and dropwise condensation.

Books Recommended

1. G.B. Wallis, One dimensional two-phase flow, McGraw Hill, 1969.
2. J.B. Collier and J.R. Thome, Convective boiling and condensation, Oxford Science Publications, 1994.
3. Cebeci,T. and Bradshaw, P., Physical and Computational Aspects of Convective Heat Transfer, Springer-Verlag, 1984.
4. Cebeci,T. and Bradshaw,P., Momentum Transfer in Boundary Layers, McGraw Hill, 1977.
5. Patankar,S.V., Numerical Heat Transfer and Fluid Flow, McGraw Hill, 1980.

ME-580	Optimization Theory	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand basic mathematical concepts of optimization
CO2	Develop modeling skills necessary to describe and formulate optimization problems
CO3	To understand different methods of optimization and be able to suggest a technique for a specific problem
CO4	Develop skills necessary to solve and interpret optimization problems in engineering.

Basic Concepts, optimal problem formulation. Single variable optimization algorithms: bracketing, region elimination, point estimation, and gradient based methods, root finding, Multivariable optimization algorithms: unidirectional search, direct search methods, simplex search and gradient based methods. Constrained optimization algorithms: penalty function method, method of multipliers, sensitivity analysis, direct search for constrained minimization, linearized search techniques, feasible direction method, generalized reduced gradient method, and gradient projection method. Nontraditional optimization algorithms: Genetic algorithms, simulated annealing, and global optimization Computer programming practice for general design applications.

Books Recommended

1. S.S. Rao, *Engineering Optimization: Theory and Practice*, New Age International Publishers,2006.
2. S.Bradley, A.Hax, T.Magnanti, *Applied mathematical programming*. Addison Wesley, 1977.
3. Rardin L. Ronald, *Optimization in operations research*, Prentice Hall. 1997.
4. Strang and Gilbert, Introduction to applied mathematics, Wellesley-Cambridge press, 1986.
5. K.Deb, *Optimization for engineering design: algorithms and examples.* Prentice Hall of India,New Delhi. 1996.
6. C.Balaji, Essentials of Thermal System Design and Optimization, Ane Books Pvt. Ltd., 2011.

ME-581	Photovoltaic Cell and its Applications	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand the physical principles of the photovoltaic (PV) solar cell and what are its sources of losses
CO2	To know the electrical (current-voltage and power-voltage) characteristics of solar cell, panel or generator and how the environment parameters influence it
CO3	To know the most important characteristics of the elements within a PV system, battery and charge controller, DC/DC converter, DC/AC converter (inverter) and loads

CO4	To understand the role of solar energy in the context of regional and global energy system, its economic, social and environmental implications, and the impact of technology on a local and global context
CO5	To know the main lines of research in the field of photovoltaic technology and solar energy.

Solar Radiation: Introduction, Measurement of Solar Radiation on Earth's Surface, Sun–Earth Angles, Solar Radiation on a Horizontal Surface, Solar Radiation on an Inclined Surface, Solar Cell Materials and Their Characteristics, Introduction, Doping, Fermi Level, p-n Junction, p-n Junction Characteristics, Photovoltaic Effect, Photovoltaic Material, Basic Parameters of Solar Cells, Effect of Cell Temperature on Cell Efficiency, Current Research on Materials and Devices, Silicon Processing.

PV Array Analysis: Introduction, Photovoltaic (PV) Module and Array, Theory and Construction, Series and Parallel Combinations, Balance of PV Array, Partial Shading of Solar Cell and Module, Maximum Power Point Tracker (MPPT), International Status of PV Power Generation.

Role of Batteries and Their Uses: Introduction, Fundamental Principles, Electro-chemical Action, Physical Construction, Discharge Characteristics, Charging Characteristics, Selection of PV Battery, Batteries Commonly Used for PV, Applications, Battery Installation, Operation and Maintenance, Battery Protection and Regulating Circuits Battery Simulation and Sizing, Battery Lifetime in a PV System, Charging State of PV-powered Storage Batteries, General Terms.

Thermal Modelling of Hybrid Photovoltaic/Thermal (PV/T) Systems: Introduction, PV/T Air Collectors, Hybrid Air Collector, Double-pass PV/T Solar Air Collector, Thermal Modelling of PV/T Air Collector, Covered by Glass-to-Tedlar Type PV Module, Thermal Modelling of PV/T Air Collector, Covered by Glass-to-Glass Type PV Module, Testing of the Solar Air Collector, PV/T Solar Water Heater, PV/T Solar Distillation System, Active PV/T Distillation System, PV/T Solar Dryers,Statistical Analysis

Energy and Exergy Analysis: Energy Analysis, Energy Matrices, Embodied Energy, Embodied Energy of PV Module (Glass-to- Glass) Balance of System (BOS), Analysis of Embodied Energy and EPBT of PV/T Solar Systems, Energy Pay-back Periods of Roof-mounted Photovoltaic Cells, Exergy Analysis, Importance of Exergy, Exergy of a Process, Exergetic Analysis of Flat-plate Collector, Exergetic Analysis of PV/T Systems.

Economic Analysis: Introduction, Cost Analysis, Cash Flow, Cost Comparisons with Equal Duration, Cost Comparisons with Unequal Duration, Analytical Expression for Payout Time, Net Present Value, Benefit-Cost Analysis, Internal Rate of Return, Effect of Depreciation, Cost Comparisons of Solar Dryers with Duration.

Case Studies of PV/T Systems: Introduction, Different types of case study Grid-connected Building Integrated, Photovoltaic System (BIPV), PV-integrated Water-pumping Application, Simulation of an Existing BIPV System for Indian Climatic Conditions etc.

ME-582	Refrigeration Systems and Components Design	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To know about the design of various refrigeration system components
CO2	To learn some different refrigeration systems
CO3	To understand the components of vapor compression systems and other types of cooling systems
CO4	To learn about design of cold storages, mobile refrigeration system and various commercial applications of refrigeration.

Introduction to various components. Thermal design of reciprocating, centrifugal and screw compressors. Capacity control methods. Thermal design of different evaporators–DX, flooded, etc. Thermal design of condensers–water-cooled and air-cooled. Sizing of capillary. Selection of expansion valves and other refrigerant control devices. Components balancing. Testing and charging methods. Design of absorber and generator of vapor absorption systems. Design of cold storages, mobile refrigeration, refrigerators, commercial appliances.

Books Recommended

1. Arora C P, "Refrigeration and Air Conditioning", 19th Edition, Tata McGraw Hill, Delhi, 1985.
2. Pradad M, "Refrigeration and Air Conditioning", 2nd Edition, New Age International Private Limited, Delhi (2002).
3. Dossat, R J, "Principles of Refrigeration", 4th Edition, Pearson Education (Singapore), India, 2002.
4. Mcquiston F G, Parker J D and Spilter J D, "Heating, Ventilating, and Air Conditioning", 5th Edition, John Wiley and Sons Inc, New York, 2001.
5. Jordan and Prister, "Refrigeration and Air Conditioning", Prentice Hall of India, 1998.

ME-583	Renewable Energy	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To explain the basic principles of various renewable energy conversion processes and devices used therein
CO2	To identify various parameters that influences the performance of renewable energy devices/processes
CO3	To undertake the field projects in the area of solar thermal, solar PV, wind, biomass, ocean energy, geothermal etc.
CO4	To identify suitable renewable source and technology for a given requirement
	To develop the integrated renewable energy technology for decentralized power sector.

Need of sources of renewable energy, Introduction to different sources of renewable energy, e.g., Solar Energy, Wind Energy, Bio-mass, Geothermal Energy, Ocean energy, Solar Energy and Applications , Basic concepts, , Flat plate and concentrating collectors, applications such as Air Heater, water heaters, thermal energy storages, photo: voltaic cell, Wind Energy, Sources and potentials, horizontal and vertical axis windmills, performance characteristics, Augmentation of wind power, Betz criteria, Bio-Mass: Principles of Bio-mass conversion, Anaerobic/Aerobic digestion, types of Bio-gas digesters, Combustion characteristics of bio-gas and its different utilizations,

Geothermal Energy: Resources, methods of harnessing energy, Ocean Energy: Principles utilization, thermodynamic cycles, tidal and wave energy, potential and conversion technique.

Books Recommended

1. John A. Duffie and William A. Beckman, *Solar Engineering forThermal Process*, Wiley and Sons, 2013.
2. Tiwari and Ghoshal, *Renewable Energy Sources*, Narosa Publication, 2007.
3. K.Mittal, *Non-conventional energy systems*, Wheeler Publ House, 2003.
4. S.P.Sukhatme, *Solar Energy- Principles of Thermal Collection and Storage*, TMH, 2005.
5. H.P. Garg, *Solar Energy*, TMH, 1997.
6. D.P.Kothari and K.C.Singhal, *Renewable Energy Sources and emerging technologies*, PHI Learning private Ltd., 2nd edition, 2012.

ME-584	Solar Passive Design and Sustainable buildings	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understanding the basic principles and fundamentals of mechanical engineering in the building integrated passive design
CO2	To understand the interrelation of engineering and building science for sustainable development in built environment
CO3	To provide a bird eye view of Indian building compliance codes and energy efficiency measures for sustainable buildings and building integrated systems.

Introduction: Heating and cooling load of buildings: elements of heating and cooling load, load reduction approaches.

Passive heating and cooling in buildings: Direct and indirect solar passive heating systems; solarium, trombe wall, trans-wall, thermal mass, courtyard effect, wind tower design, earth air tunnel system, evaporative cooling, radiative cooling.

Green and Sustainable buildings: Concept of green buildings, features of green building rating systems in India, indoor environment issues for green buildings, Green home rating system, Concept of Net zero energy building.

Building Energy Codes: Energy Conservation Building Code: requirements of code, applicability, compliance options: prescriptive, trade-off, whole building performance methods.

Books Recommended

1. Passive and low energy cooling of building by Baruch Givoni (John Willey & Sons).
2. Advances in Passive Cooling by MatheousSantamouris (Earthscan, London).
3. Passive Building Design: A handbook of natural climate control (N K Bansal, G Hauser, GMinke).
4. Energy Conservation Building Code (ECBC, 2016), Bureau of Energy Efficiency, India.

ME-585	Thermal Behaviour of Advanced Materials	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand various strengthening mechanisms of materials
CO2	Learn about thermal behaviour of advanced materials like Ceramics, Composites, Shape memory alloys, Metglasses, and Nanostructured Materials
CO3	Understand accounting for creep in development of technologically important materials such as long-fibre composites and discontinuously reinforced composites
CO 4	Learn about heat treatment mechanisms, Conductivity and Internal thermal resistance of composites.

Basic Information about the Material, Elastic behavior of materials, concept of engineering and true stress and true strain, tensile property, yield point phenomenon & elastic modulus. Heat Treatment Processes, Strengthening Mechanisms of Materials, Basics of Thermal, Optical, Electrical and Magnetic Properties of Materials, Concepts of Creep, Fatigue, Fracture and Corrosion, Introduction to Ceramics, Composites, Shape Memory Alloys, Metglasses, and Nanostructured Materials, Thermal Behaviour of Composites, Thermal expansion and thermal stresses: Thermal stresses and strains, Thermal expansivities, Thermal cycling of unidirectional composites, Thermal cycling of laminates, Creep: Basics of matrix and fibre behaviour, Axial creep of long-fibre composites, Transverse creep and discontinuously reinforced composites, Thermal Conduction: Heat treatment mechanisms, Conductivity of composites, Internal thermal resistance.

Books Recommended

1. T. E. Reed-Hill & R Abbaschian, *Physical Metallurgy Principles,* Thomson.

2. L.H. Van Vlack, *Elements of Materials science & Engineering*, Addison Wesley Pub. Company,
3. Hull and Clyne, *An Introduction to Composite Materials*, Cambridge University Press,
4. Diwan and Bhradwaj, *Nano Composites*, Pentagon Press, New Delhi.
5. William D CallisterJr, *Materials Science and Engineering*, John Wiley & Sons, Inc.
6. G.E. Dieter, *Mechanical Metallurgy*, McGraw-Hill, London.
7. V.Raghvan, *Materials Science and Engineering*, Prentice Hall of India.

ME-586	Turbomachinery	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To understand various devices used for power production and transmission
CO2	To understand the working principles and analysis of various turbo-machines
CO3	To understand various operation difficulties involved in turbo-machines
CO4	To understand various techniques to improve the performance of various turbo-machines.

Introduction, Classification of turbo machinery. Application of Time Temperature diagram – theorem in turbo machinery. Incompressible fluid flow in turbomachines – Effects of Reynolds Number and Mach number. Energy transfer between a fluid and a rotor - Euler turbine equation – components of energy transfer – impulse and Reaction – Efficiencies, Radial flow pumps and compressors – head capacity relationship – Axial flow pumps and compressors – Degree of reaction dimensionless parameters – Efficiency and utilization factor in Turbo Machinery, Thermodynamics of Turbo machine processes – Compression and expansion efficiencies – Stage efficiency – Infinitesimal stage and finite stage efficiencies, Flow of fluids in Turbo machines – flow and pressure distribution over an airfoil section – Effect of compressibility cavitations – Blade terminology- Cascades of blades – fluid deviation – Energy transfer of blades – Degree of reaction and blade spacing – Radial pressure gradient – Free vortex flow – losses in turbo machines, Centrifugal pumps and compressors – Inlet section – Cavitation – flow in the impeller channel – flow in the discharge casing pump and compressor characteristic, Radial flow turbines – inward flow turbines for compressible fluids – inward flow hydraulic – velocity and flow coefficients – gas turbine blading – Kaplan turbine – pelton wheels.

Books Recommended

1. Lee, *Theory and Design of Steam and Gas Turbine*, McGraw Hill, 1954
2. S.M.Yahya, *Turbines, Compressions & Fans*, Tata McGraw Hill. 1983.
3. J.Lal, Hydraulic Machines, Metropolitan Books Co. Ltd, N.Delhi, 1956.

ME-587	Waste Heat Utilization and Polygeneration	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To apply the knowledge of power generation configurations for power and process heating to suit the waste heat recovery
CO2	To estimate performance of integrated energy system with suitable applications. To develop the layouts for the desalination and cooling integration
CO3	To apply the knowledge of energy storage for poly-generation. To design the heat exchangers for poly-generation with waste heat recovery
CO4	To justify the poly-generation plants with the thermos-economic evaluation.

Power generation: Review of Thermodynamics, Indian potentials and scenario for power generation, cogeneration and polygeneration. Methods of improving the current technologies.Power cycles and their limitations, organic Rankine cycle, areas of major losses.Micro turbine systems, decentralized power generation, direct conversion technologies – Thermoelectric generators, Thermoionic conversion, Thermo-PV, MHD. Combined cycle, combined gas turbine-steam turbine power plant,

heat recovery steam generators.Heat recovery vapor generators.Thermodynamic cycles for low temperature application.
Cogeneration: Topping cycle cogeneration. Industrial Examples: Process heating in sugar plants, paper and other industries. Bottoming cycle: Waste Heat Boilers, Metal industries, cement plants and potential in power plants. Case studies on cogeneration.
Desalination and Cooling: Desalination- basics. Types of desalination systems. Vapor absorption refrigeration system – concept - working – types. Case studies.
Trigeneration: Multi product polygeneration- multi fuel polygeneration - Case studies on trigeneration and polygeneation systems – Performance calculations. Efficiency of polygeneration compared to stand-alone production.
Waste heat recovery: A case study for heat recovery - potential in India. Special heat exchangers for waste heat recovery, Synthesis of heat exchanger network. Pinch technology, Selection of pinch temperature, stream splitting, process retrofit, insulation, fins, effective use of heat pumps and heat engines, heat pipes.
Design of heat recovery systems: Effectiveness, Types of heat exchangers – LMTD- effectiveness-NTU methods. Recuperative, Regenerative, run-around coils.
Energy Storage: Pumped hydro, Compressed air, Flywheel, Superconducting magnetic storage. Smart buffers (batteries, hot and cold thermal energy storage, pure water reservoirs, etc).
Techno-economics: Investment cost – economic concepts – measures of economic performance – procedure for economic analysis – examples – procedure for optimized system selection and design – load curves – sensitivity analysis – regulatory and financial frame work for cogeneration and waste heat recovery systems,Thermoeconomic optimization of polygeneration systems.

Books Recommended

1. Eastop, T.D. & Croft D.R, “Energy efficiency for engineers and Technologists”, 2nd edition, Longman Harlow, 1990.
2. EDUCOGEN – The European Educational tool for cogeneration, Second Edition, 2001.
3. Osborn, peter D, “Handbook of energy data and calculations including directory of products and services”, Butterworths, 1980.
4. Charles H.Butler, Cogeneration, McGraw Hill Book Co., 1984.
5. Horlock JH, Cogeneration - Heat and Power, Thermodynamics and Economics, Oxford, 1987.
6. Institute of Fuel, London, Waste Heat Recovery, Chapman & Hall Publishers, London, 1963.
7. Seagate Subrata, Lee SS EDS, Waste Heat Utilization and Management, Hemisphere, Washington, 1983.
8. Srinivas, T. Shankar Ganesh N and Shankar R., 2019, Flexible Kalina Cycle Systems, Taylor and Francis Publishers, CRC press, ISBN: 9781771887137.

ME-588	Science, Technology and Engineering Projects for Sustainability	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	To familiarize about the various engineering/socio-economic problems.
CO2	Use of engineering tools for creative/innovative solutions.
CO3	Evaluation and analysis of solutions.
CO4	Create self-employment opportunities.

Introduction: Status of research and innovation worldwide with respect to advancement in technology.
Patenting and publishing: Intellectual property right (IPR) related laws, rules and issues at national and

international level.
Problem finding and literature survey: Information gathering – reading, searching and documentation; types, attributes and sources of research problems; problem formulation. Problems associated with sustainability as per the need of 21st century in developed and developing countries.
Funding agencies for projects: Various funding agencies in India, How to approach funding agencies, how to apply for a project through funding agencies, venture capitalist approach.
Startup Schemes: Government/Institution support for startups, Different startup schemes in India and worldwide.

Recommended Books

1. E.M. Phillips and D S Pugh, -How to get a PhD – a handbook for PhD students and their supervisors‖, Viva books Pvt. Ltd for all scholars irrespective of their disciplines.
2. Peter B Medeq, -Advie to a Young Scientist‖, Pan Books, London, 1979.
3. S.P. Ladas, - Patents, Trademarks, and Related Rights: National and International Protection (Vol. 1). Harvard University Press, 1975.

ME-589	Solar Thermal Technologies	(3 0 0 3)

Course Outcomes: At the end of the course the student will be able to:

CO1	Understand the solar geometry and measurement of solar radiation for the estimation.
CO2	Apply the sun-earth relation to estimate the solar radiation at given conditions and validation.
CO3	Analyze the performance of solar thermal energy collectors with energy conversion into heat.
CO4	Evaluate solar thermal energy storage such as scribble heat storage, latent heat storage, thermos-chemical heat storage.
CO5	Understand the working of solar thermal technologies and design of solar thermal devices.
CO6	Analyze the solar thermal system with the economics.

1. Collection
Solar Geometry: sun earth relations, incidence angle, tilt orientations.
Solar Radiation: Solar radiation outside the earth's atmosphere, solar radiation at the earth's surface, instruments for measuring solar radiation and sunshine, solar radiation data, solar radiation on tilted surfaces.
Solar Water Heaters: Flat – Plate collectors: Transmissivity of cover system, physical principles of conversion of solar radiation into heat, energy balance equation and collector efficiency, Natural circulation water heater; (pressurized and non-pressurized) Forced circulation solar water heater, space heating and cooling.
Solar Concentrators: Solar concentrator types – Optics – Performance analysis – Design considerations – Tracking.

2. Storage
Thermal Energy Storage: Scribble heat storage, latent heat storage, thermo-chemical heat storage.

3. Utilization
Solar Air Heaters and drying: Working principle: Open sun drying, direct solar drying, and indirect solar drying.

Solar Thermal Devices: Solar Distillation - Solar Pond and other Applications - Worming Principle, principle and description of solar pond and operational problem, collection – cum storage water heater, Green house, solar cooker, heating of biogas plant by solar energy.
Solar Thermal Power Generation: Solar Electric Power Generation Systems – Economics of Solar thermal systems & devices.

Recommended Books

1. J. A. Duffie, and W. A. Beckman, (1991) Solar Engineering of Thermal Processes, Wiley-Interscience.
2. Y. Goswami, F. Kreith and J. F. Kreider, (2001), Principles of Solar Engineering, Mc Graw Hill,
3. S.P.Sukhatme, Solar Energy, (2004), Tata McGraw Hill, Second Edition.
4. J. Gordon (ed.) (2001) State of Art Papers on Solar Energy, International Solar Energy Society.
5. ASHRAE Standard 93-77, (1977) Methods of Testing to Determine the Thermal Performance of Solar Collectors, ASHRAE.
6. R.C.Neville, (1995) Solar Energy Conversion, Elsevier.
7. Boca Raton,Hand book of energy efficiency and renewable energy, CRC Press, 2007.