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

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<u>Annexure-F</u>

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", 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. 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, 2^{nd} 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)