Savitribai Phule Pune University
(Formerly University of Pune)

Board of Studies, Department of Technology
Mechanical & Materials (MM) Technology
Curriculum Structure for M.Tech Program

Sr. No.	Subject Code	Subject Name	Credits	Teaching Scheme (Theory)	Teaching Scheme (Lab)
Semester (I)					
1	MMaths	Mathematics for Technology	3	√	
2	MMC2	Advance Stress Analysis	3	√	
3	MMC3	Advance Thermofluids-I	3	√	
4	MMC4	Nanotechnology	3	√	
5	MME*	Elective-1	3	√	
6	MMLP1	Lab Practice - 1	3		√
7	MMSM1	Seminar - 1	1		√
Semester (II)					
8	MMC5	Computer Aided Engineering	3	√	
9	MMC6	Theory of Vibration and Noise Control	3	√	
10	MME7	Robotics	3	√	
11	MME8	Smart Materials	3	√	
12	MME*	Elective-2	3	√	
13	MMLP2	Lab Practice - 2	3		√
14	MMSM2	Seminar - 2	1		√
Semester (III)					
15	TSD	Technical Skill Development	3	√	
16	MMD2	Elective-3	3	√	
17	MMIntProj	Interim Project	10		√
Semester (IV)					
18	MMFinProj	Final Project (Dissertation Submission)	16		√
		TOTAL CREDITS	70		

AUDIT COURSES				
Sr. No.	**Subject Code**	**Subject Name**	**Credits**	**Semester**
1	CYSA	Cyber Security	2	I
2	HRE101	Human Rights & Duties	1	I
3	HRE102/HRE103	Human Rights & Vulnerable Groups/Law Policy , Society & Enforcement mechanism	1	II

Notes:

1) Electives can also be Open Electives in spirit of CBCS.
2) Maximum 25% Open Electives are allowed.
3) Candidates are expected to perform minimum three (3) assignments for every Lab Practice, and submit report as a bona fide document to supervisor/course instructor. The assignment may be in the form of modeling/ simulation/ programming/ experimental investigation/ fieldwork
4) The candidates are expected to select three electives from the list provided in Table(s) in this document

LIST OF ELECTIVES FOR MECHANICAL & MATERIALS BOARD

Sr. No.	Subject Code	Subject Name
1	MME1	Advanced Stress Analysis
2	MME2	Vehicle Dynamics
3	MME3	Engineering Fracture Mechanics
4	MME4	Computational Geometry
5	MME5	Advanced Machine Tool Design
6	MME6	Analysis and Synthesis of Mechanism
7	MME7	Advanced Thermodynamics
8	MME8	Advanced Heat Transfer
9	MME9	Advanced Fluid Mechanics
10	MME10	Computational Fluid Dynamics
11	MME11	Refrigeration Technology
12	MME12	Industrial Automation
13	MME13	Advanced Gas Dynamics
14	MME14	Advanced Air conditioning and Heating and Ventilation
15	MME15	Internal combustion Engines
16	MME16	Advanced Physical and Mechanical Metallurgy
17	MME17	Microcontrollers
18	MME18	Drives and Actuators
19	MME19	Tribology
20	MME22	Advanced Manufacturing Process
21	MME23	Advanced Materials
22	MME24	Advance Thermofluids-II

23	MME25	Manufacturing System Design
24	MME26	Finite Element Methods
25	MME27	Combustion
26	MME28	Instrumentation and Process Control
27	MME29	Advance Manufacturing Methods
28	MME30	Advance Corrosion
29	MME31	Acoustics
30	MME32	Advances in Iron and Steel Production
31	MME33	Automation in Manufacturing Systems
32	MME34	Automotive Transmission System Design
33	MME35	Advanced Materials & Processing
34	MME36	Product Life Cycle
35	MME37	Advanced Heat & Mass Transfer
36	MME38	System and equipment designed for direct mixing steam condenser
37	MME39	Material and devices for energy storage
38	MME40	Modelling and cooling system for high performance computing
39	MME41	Semiconductor Nano structure for solar cell application
40	MME42	Fluid Power Engineering
41	MME43	Nanotechnology
42	MME44	German Language for Technology
43	MME45	High Explosives and Under Water Explosion
44	MME46	Design and Analysis of Scanning Mechanism
45	MME47	Automotive Materials
46	MME48	Machine Design With Statistical Approach

47	MME49	Passive Techniques for Heat Transfer Enhancement
48	MME50	Non-Linear Vibration
49	MME51	Additive Manufacturing Process
50	MME52	Artifact in Coordinates Measuring
51	MME53	Design and Fabrication of rechargeable batteries with mimics of flexibility
52	MME54	Advanced Statistics
53	MME55	Advanced Mechatronics
54	MME56	Advanced Stress Analysis
55	MME57	Solar Energy and its Applications
56	MME58	Smart Materials
57	MME59	Advances in IC engines
58	MME60	Advanced Vibration and noise control
59	MME61	Optimization Techniques
60	MME62	Surface Engineering and Tribology
61	MME63	Advanced Machine Design
62	MMDS1	Metal working Tribology
63	MMDS2	Energy Storage Device: Super capacitor
64	MMDS3	CAD Software Customization
65	MMDS4	Computer Simulation & Analytical Tools
66	MMDS5	Analysis and Optimization of Gear Box

Programme Outcomes

Programme issues are narrower checks that describe what the scholars are hoped to undergo and be qualified to do upon the scale. They relate the knowledge, chops and geste the scholars develop through the Programme. The Programme issues(PO) are specific to the Programme and are harmonious with the Graduate Attributes and grease the attainment of PEOs.

At the end of the Programme the Students shall be suitable to

Program Learning Outcomes:

1. Apply Technological knowledge
2. Identify and Analyse knowledge to solve branch specific problems
3. Carryout independent study of design and development work to break practical problems.
4. Ability to conduct experiments, Demonstrate a degree of mastery in Materials, design and thermal at a position advanced than the Bachelor's Programme.
5. Develop algorithms using commercial and open source tools and breakthrough the ways in mechanical with optimal results.
6. Societal needs, environment concerns and sustainable developments
7. Individual task and Team work
8. Engage in lifelong literacy clinging to professional, ethical, legal, safety, environmental and societal aspects for career excellence.

MATHEMATICS FOR TECHNOLOGY

Course Code: MMaths **Credit Units: 03 Credits**

Course Content:

Unit 1: Numerical differentiation I:

Partial differential equation Laplace and Poisson's equation-solution, method of characteristics for solution of initial boundary value problems, relaxation method

Unit 2: Numerical differentiation II:

Finite Difference, Gaussian elimination and Gauss, Jordan methods, matrix inversion, Gauss Seidel method –Newton- Raphson method

Unit 3: Statistics and Probability:

Moments, Skewness and Kurtosis, Probability, conditional probability, various theoretical distributions like binomial, normal, log-normal, Poisson, gamma distribution, Pearson type I, II & II distribution test of significance, Gumbel distribution, testing of hypotheses – Large sample tests for mean and proportion, Chi-square test, errors, types of errors.

Unit 4: Regression and Correlation:

Regression and correlation – rank correlation – multiple and partial correlation – analysis of variance-one way and two way classifications – experimental design – Latin square design

Unit 5: Transforms:

Laplace Transformer: LT of standard function, inversions and their application in civil engg. Fourier Transformer: Fourier integral, Fourier transform and their application in civil engg.

Unit 6: Matrix method and Finite element:

Matrix method analysis (Stiffness) coordinate calculation for different types of structure. Finite element method basics (1D and 2D) coordinate calculations.

COURSE OUTCOMES

By the end of the semester, the student will be able to:

- Apply elementary transformations to reduce the matrix into the echelon form and normal form to determine its rank and interpret the various solutions of system of linear equations
- Identify the special properties of a matrix such as the eigen value, eigen vector, employ orthogonal transformations to express the matrix into diagonal form, quadratic form and canonical form
- Equip themselves familiar with the functions of several variables and mean value theorems

- Familiarize with special functions to evaluate some proper and improper integrals using beta and gamma functions

Reference Books

1. Higher Engineering Mathematics by B. S. Grewal (Khanna Publication, Delhi).
2. Venkatraman, M.K., Numerical Methods in Science and Engineering, National Publisher Company.
3. Numerical Methods by Krishna Raju
4. Shanthakumar M.S., Numerical Methods & Analysis
5. Gupta, S.C. and Kapur, V.K., "Fundamentals of Mathematical Statistics ", Sultan Chand & Sons, New Delhi, 1999.

Advanced Stress Analysis

Course Code: MMC2 **Credit Units: 03 Credits**

Course Content:

Analysis of stress, Analysis of stain, Elasticity problems in two dimension and three dimensions, Mohr's circle for three dimensional stresses,stress tensor, Airy's stress function in rectangular & polar coordinates, energy method for analysis of stress, strain and deflection, the three theorem's -theorem of virtual work, theorem of least work, Castigliano's theorem, Rayleigh Ritz method, Galekin's method, Elastic behaviour of anisotropic materials like fiber reinforced composites

Torsion of prismatic bars of solid section and thin walled section, analogies for torsion, membrane analogy, fluid flow analogy and electrical analogy, torsion of conical shaft, bar of variable diameter, thin walled members of open cross section in which some sections are prevented from warping, torsion of noncircular shaft.

Concept of shear centre in symmetrical and unsymmetrical bending, stress and deflections in beams subjected to unsymmetrical bending, shear centre for thin wall beam cross section, open section with one axis of symmetry, general open section, and closed section

Bending of plate to cylindrical surface, bending of a long uniformly loaded rectangular plate, pure bending in two perpendicular directions, bending of circular plates loaded symmetrically w. r. t. center, Bending of circular plates of variable thickness, circular plate with circular hole at center symmetrically loaded and load distributed along inner and outer edges

Governing equations, stress in thick walled cylinder under internal and external pressure, shrink fit compound cylinders, stresses in rotating flat solid disk, flat disk with central hole, disk with variable thickness, disk of uniform strength, plastic action in thick walled cylinders and rotating disc

Geometry of contact surfaces, method of computing contact stresses and deflection of bodies in point contact, stress for two bodies in line contact with load normal to contact area and load normal and tangent to contact area, introduction to analysis of low speed impact

Introduction to Linear Elastic Fracture Mechanics, modes of fractures, stress intensity factor, crack initiation and crack opening phenomenon, stress distribution around crack tip under various loading conditions, fracture toughness G_{Ic}plastic bending of elastic materials, post yield stress analysis, plastic flow process, shape factor, spring back effect

Dimensional analysis, analysis techniques strain gauges: configuration, instrumentation, characteristics of strain gauge measurement, theory of photo-elasticity and techniques used in photoelastic application

Course Learning Outcomes

After learning the course the students should be able to:

1. Analyze stresses in components subjected to various loading.
2. Apply concepts of theory of failure mode analysis.
3. Analyze structures idealized as plates.
4. Analyze contact stresses in complex components forced against each other

Mini project:-

On FEM analysis of machine members by using reputed commercial software for stress distribution, stress concentration and report writing on results of analysis.

References

1. Cook and Young, Advanced Mechanics of Materials, Prentice Hall
2. Richard G. Budynas, Advanced Strength and Applied Stress Analysis, McGraw Hill
3. Boresi, Schmidt, Sidebottom, Advanced Mechanics of Materials, Willey
4. Timoshenko and Goodier, Theory of Elasticity, McGraw Hill
5. Timoshenko, Advanced Strength of Materials, Vol. 1,2, CBS
6. Den Harteg, Advanced Strength of Materials
7. Dally & Riley, Experimental Stress Analysis
8. Timoshenko, Theory of Plates and Shells, McGraw Hill
9. Hertzberg R. W.,Deformation and Fracture Mechanics of Engineering Materials, 4th edition, John Wiley & Sons, Inc., 1996.

Advanced Thermofluids-I

Course Code: MMC3 **Credit Units: 03 Credits**

Course Content:

An introduction to mechanical engineering thermodynamics dealing with the application of the first and second laws of thermodynamics to the thermodynamic design and performance analysis of typical thermo-mechanical plant using condensable vapors and gases as the working fluid. Basic fluid mechanics including: kinematics and dynamics of fluid flows; conservation laws applied to fluid flow; Euler, Bernoulli, Navier-Stokes equations; dimensional analysis; differential and integral flow analysis; flow visualization.

Mass, momentum and energy equations in differential and integral forms, one dimensional applications, external boundary layers(hydrodynamic and thermal, internal flows with heat transfer, natural convection, boiling and condensation.

Course Learning Outcomes

On the completion of this course students are expected to be able to:

1. Understand and be able to apply fundamental concepts and equations to practical problems;
2. Have a good understanding of basic thermodynamics and its importance in thermal systems;
3. Have a deep understanding of the different forms of energy, its transfer and the laws that controls this transfer;
4. Be equipped with the knowledge of environmentally responsible and current best practice for the design of efficient thermal system and cycles;
5. Have developed analytical skills and problem solving skills in advanced thermodynamics and fluid mechanics

Term Work

Exercise / Assignments for Laboratory Practice – I

A) Study and report on:-

1. Fluid-Structural interaction under thermal conditions
2. Open Foam tutorials for electronic cooling

B) Mini project:-

On FEM analysis of machine members by using reputed commercial software for transient and steady state, and report writing on results of analysis.

References

- Two parts of Thermo-Fluids 1 Lecture Notes: Thermodynamics part and Fluid Mechanics parts, and Level 2 Labbook – all available from the Image & Copy Centre.
- Moran, M.J., Shapiro, H.N., D. D. Boettner & Bailey, M. B., Principles of Engineering Thermodynamics, John Wiley and Sons Inc, 8th Edition 2015 Wiley or
- Moran, M.J., Shapiro, H.N., D. D. Boettner & Bailey, M. B., Fundamentals of Engineering Thermodynamics, John Wiley and Sons Inc, 7th Edition 2011 Wiley

Nanotechnology

Course Code: MMC4 **Credit Units: 03 Credits**

Course Content:

Syllabus Contents:

Unit I: Introduction to Nanotechnology (6 hrs)

Basic concepts of Nanoscience and Nanotechnology, Nanoscale-Interesting about nanoscale, Nanostructures, classification of nanomaterials based on their dimensionality, General properties of nanomaterials, Fundamental issues, importance of nanomaterials, toxicity of nanomaterials, semiconductor and nanocomposites.

Unit II: SYNTHESIS OF NANOMATERIALS (6 hrs)

Introduction, Synthesis approach: Bottom-up and Top-down. Physical methods: Mechanical ball milling method, photolithography, Chemical methods: sol-gel synthesis, microemulsion synthesis, Biological methods: plant extract, bacterial synthesis.

Unit III: PROPERTIES OF NANOSTRUCTURES AND MATERIALS (6 hrs)

Electronic properties: Quantum confinement, Quantum size effect, Energy bands and electronic transition, Charge quantization

Optical properties: Semiconductor, metal nanoparticles, size and shape dependency, surface plasmon resonance and quantum size effects. Magnetic properties: Magnetism, effect of size on magnetization, Thermal Properties nd Mechanical Properties: Yield strength, Tensile

strength, Ductility, Toughness etc.

Unit IV: CARBON NANOSTRUCTURES (6 hrs)

Introduction, Carbon nanotubes: Discovery, structure, types, properties, synthesis and potential applications. Fullerene: Structure, properties and potential applications. Graphene: Structure, properties and potential applications.

Unit V: MATERIAL CHARACTERIZATION TECHNIQUES (6 hrs)

Compositional and structural Characterization techniques: X-Ray diffraction, Scanning Electron Microscopy, Transmission Electron Microscopy, Spectroscopic techniques: Uv-

Visible, Infrared, Electrical characterization techniques, Thermal characterization: Thermo Gravimetric Analysis, Differential Thermal Analysis, Differential Scanning Calorimetry analysis.

Unit VI: NANO TECHNOLOGY APPLICATIONS (6 hrs)

Lithium Ion batteries, Fuel Cells, Agriculture, water purification, electronics, hydrogen storage.

Course Outcomes:

At the end of the course, students will be able to:

1. CO1: To understand the basic science behind the design and fabrication of nano scale
2. Systems.
3. CO2: To understand and formulate new engineering solutions for current problems and competing technologies for future applications.
4. CO3: To be able make inter disciplinary projects applicable to wide areas by clearing and fixing the boundaries in system development.
5. CO4: To gather detailed knowledge of the operation of fabrication and characterization devices to achieve precisely designed systems.

Text Books & References:

1. Nano: The Essentials -Understanding Nano Science and Nanotechnology byT.Pradeep, TataMc.Graw Hill
2. Introduction to Nano Technology by Charles. P. Poole Jr and Frank J. Owens, WileyIndia Pvt Ltd.
3. A practical approach to X-Ray diffraction analysis by C.Suryanarayana
4. Electron Microscopy and analysis by P.J. Goodhew and F.J. Humpreys
5. Scanning electron microscopy and x-ray microanalysis by J.I. Goldstein
6. Characterization of nanostructured materials by Z.L. Wang
7. Modern Raman Spectroscopy: A practical approach by E. Smith and G.Dent
8. Principles of Instrumental analysis by D.A. Skoog, F.J. Hollen and T.A. Niemann
9. Atomic and Molecular Spectroscopy: Basic Aspects and Applications by S.Svanberg
10. Fuel cell Technology Handbook by Hoogers, CRC Press
11. Hand book of fuel cells: Fuel cell technology and applications by Vielstich,Wiley:CRC Press
12. Hand book of Nano structured materials Vol I & V
13. Encyclopedia of Nano Technology by H.S.Nalwa

Advanced refrigeration

Course Code: MME11 **Credit Units: 03 Credits**
Course Content:

Vapour Compression refrigeration: Multi-evaporator system; Multi expansion system; Cascade systems; Study of P-h; T-s; h-s and T-h charts for various refrigerants, Concept of Heat Pump

Refrigerant: Designation, selection, desirable properties, refrigerant blends, secondary refrigerants, refrigerant recycling, reclaim and charging, alternative refrigerants, refrigerant-lubricant mixture behavior, ODP, GWP concepts

Vapour absorption refrigeration: Standard cycle and actual cycle, thermodynamic analysis, Li-Br-water, NH3-water systems, three fluid absorption systems, half effect, single effect, single-double effect, double effect, and triple effect system

Non-convention refrigeration system (Principle and thermodynamic analysis only): Thermoelectric refrigeration, thermo-acoustic refrigeration, adsorption refrigeration, steam jet refrigeration, vortex tube refrigeration, and magnetic refrigeration.

Compressor rating and selection- reciprocating, screw, Scroll and centrifugal compressors based on applications

Evaporators: types, thermal design, effect of lubricants accumulation, draining of lubricants, selection and capacity control

Condenser: types, thermal design, purging, selection and capacity control

Selection of expansion devices, Design of refrigerant piping refrigeration system controls and safety devices, Solenoid valves, suction and evaporator pressure regulators, Thermal Insulation

Motor selection: single phase, three phase, starters, constant speed and variable speed drive

Associated devices: high pressure receiver thermal design of low pressure receiver, accumulator, filters, driers, oil separators, relief valves, safety valves, high and low pressure cut out, thermostats, water regulators etc.

Case studies to be dealt with selection and design of various components for various Industrial refrigeration applications: Cold storage, Process applications - textile, pharmaceuticals, chemical, transport, etc.

Term Work

1. Trial on VCC as Heat pump
2. Trial on VCC- Effect of condensing and evaporator temperature on Performance
3. Visit report on (Any Two)

(a) Cold Storage
(b) Ice Plant/Dairy
(c) Pharmaceutical
4. Design of Vapor Absorption System 100 kW or 200 kW or 300 kW etc.

References

1. R.J. Dossat, Principles of refrigeration, Pearson Education Asia
2. C.P. Arora, Refrigeration and Air-Conditioning
3. Stoecker and Jones, Refrigeration and Air-conditioning
4. Jordan and Priester, Refrigeration and Air-conditioning
5. A.R. Trott, Refrigeration and Air-conditioning, Butterworths
6. J.L. Threlkeld, Thermal Environmental Engineering, Prentice Hall
7. W.F. Stoecker, Industrial Refrigeration Handbook, McGraw-Hill
8. John A. Corinchock, Technician's guide to Refrigeration systems, McGraw-Hill
9. P.C. Koelet, Industrial Refrigeration: Principles, design and applications, Mcmillan
10. ASHRAE Handbook (i) Fundamentals (ii) Refrigeration
11. ISHRAE handbooks
12. ARI Standards
13. Refrigeration Handbook, Wang, Mc Graw Hill, Int.

Computer Aided Engineering [CAE]

Course Code: MMC5 **Credit Units: 03 Credits**

Course Content:

1. CAD: Geometric Modeling- Curves – Introduction, Analytical curves (Line, circle, ellipse, parabola, hyperbola), Synthetic curves (Hermite Cubic Spline, Bezier, B-Spline Curve) [Numerical on Line, Circle, Ellipse, Hermite Cubic**,** Spline, Bezier] Surfaces – Introduction, Surface representation, Analytic surfaces, Synthetic Surfaces, Hermite bicubic, Bezier, B-Spline, Coons patch surface, Applications in freeform surfaces .Solids - Introduction, Geometry and Topology, Solid Representation, Boundary Representation, Euler's equation, Constructive Solid Geometry (CSG), Boolean operation for CSG.

2. CAM: Introduction to Computer Aided Manufacturing (CAM), Coordinate system, Working principal of CNC Lathe, Turning Centers, Milling Machine, Steps in developing CNC part program, Tool and geometric compensations, subroutine and Do loop using canned cycle. [Only theory – 2 hrs] CNC Lathe part programming (FANUC) : Linear and circular interpolation, Canned cycles for facing, threading, grooving, etc. [Theory + Program] CNC Milling part programming (FANUC): Linear and circular interpolation, Pocketing, contouring and drilling cycles.

3.CAE: Finite Elements and Formulation of 1D and 2D Elasticity Problems. Introduction, Steps to solve Springs, 1D Rod Elements, Truss elements. shape functions – linear & quadratic, displacement function – criteria for the choice of the displacement function, polynomial displacement functions, displacement function in terms of nodal parameters, strain-nodal parameter relationship, stress-strain relationship, CST element, element stiffness matrix, convergence of iso parametric elements, numerical

4.CAE: Plate and Shell Elements
Introduction, 2D Plate problems, thin and thick plates – Kirchoff theory, Mindlin plate element, triangular and rectangular, conforming and nonconforming elements, degenerated shell elements, reduced and selective integration, shear locking and hour glass phenomenon
5. CAE: Dynamic Problems – Eigen value and Time Dependent Problems, Formulation of dynamic problems, consistent and lumped mass matrices, Solution of eigenvalue problems – transformation methods, Jacobi method, Vector Iteration methods, subspace iteration method, Forced vibration – steady state and transient vibration analysis, modeling of damping, the mode superposition scheme,
Linear buckling analysis, adaptive finite element technique, error estimation, h & p refinements,
6. Computer Aided Product Design and Development:
Introduction, Steps in Product design, Product proving and Quality Testing. QFD and applications, Reverse Engg and steps. CAPP and GT overview, 3D Printing, Types, applications Rapid Tooling and STL format, Concept of 4D Rapid Prototyping.

List of References
1.Ibrahim Zeid and R. Sivasubramanian - CAD/CAM - Theory and Practice Tata McGraw Hill Publishing Co. 2009
2.S. K. Sinha, CNC Programming using Fanuc Custom Macro B, McGraw-Hill Professional
3. Seshu P., “Text book of Finite Element Analysis”, PHI Learning Private Ltd., New Delhi, 2010.
4. Mukhopadhyay M and Sheikh A. H., “Matrix and Finite Element Analyses of Structures”, Ane Books Pvt. Ltd., 2009.
5. Bathe K. J., “Finite Element Procedures”, Prentice-Hall of India (P) Ltd., New Delhi.
6. Chandrupatla T. R. and Belegunda A. D., “Introduction to Finite Elements in Engineering”, Prentice Hall India.
7. Reddy, J. N., “An Introduction to The Finite Element Method”, Tata McGraw Hill, 2003.

Theory of Vibration and Noise Control

Course Code: MMC6 **Credit Units: 03 Credits**
Course Content:

Multi degree freedom system, free vibration equation of motion, influence coefficient i) stiffness coefficient (ii) flexibility coefficient, generalized coordinates, coordinate couplings, Langrange’s equations matrix method eigen values eigen vector problems, modal analysis, forced vibrations of un-damped system and modal analysis

Multi degree system numerical methods, (i)Rayleigh’s method, (ii)Rayleigh-Ritz method (iii) Holzer’s method (iv)methods of matrix iterations (v) transfer matrix method, impulse response and frequency response functions

Continuous system, vibrations of string, bars, shafts and beams, free and forced vibration of continuous systems, transient vibrations, response of a single degree of freedom system to step and any arbitrary excitation, convolution (Duhamel's) integral, impulse response functions

Vibration control, balancing of rotating machine, in-situ balancing of rotors, control of natural frequency introduction of damping, vibration isolation & vibration absorbers

Vibration measurement, FFT analyzer, vibration exciters, signal analysis,time domain & frequency domain analysis of signals, experimental modal analysis, machine conditioning and monitoring, fault diagnosis

Random vibrations, expected values auto and cross correlation function, spectral density, response of linear systems, and analysis of narrow band systems

Nonlinear vibrations, systems with non-linear elastic properties, free vibrations of system with non-linear elasticity and damping, phase-plane technique, Duffing's equation, jump phenomenon, limit cycle, perturbation method

Noise and its measurement, sound waves, governing equation its propagation**,** fundamentals of noise, decibel, sound pressure level, sound intensity, sound fields, reflection, absorption and transmission, noise measurement, sound meter, allowed exposure levels and time limit by BIS, octave band analysis of sound, fundamentals of noise control, source control, path control, enclosures, noise absorbers, noise control at receiver

Term work

Any three from Sr. No 1 to 5 & Sr. No 6 compulsory

1. Determination of natural frequencies & modal analysis of machine components. Equipment to be used: FFT analyzer, with impact hammer or exciter, necessary transducers etc.
2. Condition monitoring & fault finding of machines by using FFT Analyzer, vibration meter, vibration pickups, transducers etc.
3. Noise measurement & analysis, equipment to be used: noise measurement & analysis instruments.
4. In-situ (on-line) balancing of rotors.
5. Problems of numerical methods of vibrations.
6. Assignment on solving vibration problems using Matlab.

Course Outcomes

1. Mathematical Modeling of SDOF Systems and estimation of natural frequencies, damping factors.
2. Forced Vibration Analysis of SDOF Systems, Vibration isolation and vibration measuring instruments.
3. Mathematical modeling of 2DOF systems, design of undamped dynamic vibration absorber, fundamentals of modal analysis.
4. Learning techniques of vibration monitoring and fundamentals of sound/noise. Learning techniques of noise control for welfare of human being

References

1. W T Thomson, Theory of Vibrations with Applications, CBS Publishers Delhi
2. S S Rao, Mechanical Vibrations, Addison-Wesley Publishing Co.
3. Leonard Meirovitch,Fundamentals of Vibration, McGraw Hill International Edison.
4. Ashok Kumar Mallik, Principles of Vibration Control, Affiliated East- West Press.
5. A H Church,Mechanical Vibrations,John Wiley & Sons Inc
6. J P Den Hartog,Mechanical Vibrations,McGraw Hill.
7. Srinivasan,Mechanical Vibration Analysis, McGraw Hill.
8. G K Groover,Mechanical Vibrations
9. Kewal Pujara, Vibration and Noise for Engineers, Dhanpat Rai & co.

Robotics

Course Code: MMC7 **Credit Units: 03 Credits**

Course Content:

Mechatronics

Introduction to theoretical and applied mechatronics, design and operation of mechatronics systems; mechanical, electrical, electronic, and opto-electronic components; sensors and actuators including signal conditioning and power electronics; microcontrollers—fundamentals, programming, and interfacing; and feedback control. Includes structured and term projects in the design and development of proto-type integrated mechatronic systems.

Foundation of Robotics

This course presents the concepts, techniques, algorithms, and state-of-the-art approaches for mobile robots and robot manipulators covering modeling, control and simulation. The class will focus on direct and inverse kinematics problem, Denavit-Hartenberg representation, Euler and RPY angles, homogeneous transformations, Manipulator Jacobian, differential relationships, force and moment analysis, inverse Jacobian, trajectory generation and path planning. The final part will involve robot arm dynamics and PD and PID controllers for robotic manipulators, practical robotic system implementation aspects, limitations and constraints, and sensors and actuators. The students will practice these concepts using Matlab or an equivalent simulation environment.

Mathematics for Robotics

The student who completes this course will gain a fundamental understanding of the principles underlying mathematics and numerical methods for dynamical systems, with particular reference to robotic systems. He/she will be able to use mathematical tools and computational methods for formulating and solving the modeling, estimation, planning, optimization, and control problems related to robotic systems. The course will employ real-world robotics examples throughout the introduction to and applications of mathematical, numerical and simulation approaches.

Course Outcomes: After doing this course, the student should be able to,

1. Understand the evolution, classification, structures and drives for robots.
2. Teach the students about the kinematic arrangement of robots and its applications in the area of manufacturing sectors.

Smart Materials

Course Code: MMC8 **Credit Units: 03 Credits**

Course Content:

Materials demand for Extreme conditions of operation, material property mapping, Processing, strengthening methods, treatment and properties of Superalloys, creep resistance, Ultra high strength steels, Light metal alloys and metal matrix composites (MMC), their applications in aerospace and automobiles, Super-plastic materials,

Materials in the vicinity of nuclear fissile fuels, zirconium alloys, stainless steels, Intermetallics, Metallic glasses, Amorphous alloys, rapid solidification, synthesis by mechanical alloying, SMART materials, shape memory effect, Functionally graded materials, Damage Tolerant Material, Bio-Materials, Nano materials, Surface engineering for modifying abrasion, wear, corrosion and fatigue performance,

Preparation of the substrate, Physical Vapour Deposition, Chemical Vapour Deposition, Ion Implantation, Coatings for high temperature performance, Electrochemical and spark discharge and Plasma coating methods, electron beam and laser surface processing, Organic and Powder coatings, Thermal barrier coating.

Advanced Manufacturing Processes

Course Code: MME22 **Credit Units: 03 Credits**

Course Content:

Non-Traditional Machining: Introduction, need, AJM, Parametric Analysis, Process capabilities, USM –Mechanics of cutting, models, Parametric Analysis, WJM –principle, equipment, process characteristics, performance, EDM – principles, equipment, generators, analysis of R-C circuits, MRR, Surface finish, WEDM.

Laser Beam Machining: Principle of working, equipment, Material removal rate, Process parameters, performance characterization, Applications. Plasma Arc Machining – Principle of working, equipment, Material removal rate, Process parameters, performance characterization, Applications. Electron Beam Machining - Principle of working, equipment, Material removal rate, Process parameters, performance characterization, Applications. Electro Chemical Machining – Principle of working, equipment, Material removal rate, Process parameters, performance characterization, Applications.

Processing of ceramics: Applications, characteristics, classification. Processing of particulate ceramics, Powder preparations, consolidation, Drying, sintering, Hot compaction, Area of application, finishing of ceramics.

Processing of Composites: Composite Layers, Particulate and fiber reinforced composites, Elastomers, Reinforced plastics, MMC, CMC, Polymer matrix composites.

Course Outcomes:

1. At the end of the course, the student will be able to understand the working principle of Electron beam, laser beam and laser beam processes.
2. Able to understand different types of composite material characteristics, types of micro &macro machining processes.
3. Understand the e-manufacturing & nano materials, 3D printing.

Optimization Techniques

Course Code: MME61 **Credit Units: 03 Credits**

Course Content:

Basic Concepts, Functions of one variable, Unconstrained Functions of N Variables, Constrained Functions of N Variables: Linear Programming, Sequential Unconstrained Minimization Techniques, Direct Methods, Approximation Techniques, Duality

Discrete Variable Optimization and Multi-Objective Optimization, Structural Optimization, General Design Applications and Multidiscipline Design Optimization, Optimization Software

Sizing, Shape and Topology/ Topography Optimization, Design Sensitivity Analysis

Optimization by ANN and GA techniques

Optimization of Systems for specific application like acoustics, laminated composite materials etc.

Course Outcome:

1. Understand basic mathematics and numerical aspects of optimization techniques.
2. Formulate objective functions of real-life problems.
3. Understand the concept of optimality criteria for various types of optimization problem.
4. Analyse optimization algorithms for Linear Programming
5. Solve various constrained and unconstrained nonlinear programming problems.
6. Apply the modern optimization methods and evolutionary techniques to provide optimal solution for a given problem.

References

1. Raphael Haftka and Zafer Gurdal, Elements of Structural Optimization, Kluwer Academic Publishers
2. Jasbir Arora, Optimization of Structural and Mechanical Systems, World Scientific
3. Garret N Vanderplaats, Numerical optimization techniques for engineering design, Vanderplaats Research and Development, Inc

Finite Element Method

Course Code: MME26 **Credit Units: 03 Credits**

Course Content:

Methods of weighted residual, weak formulation, piecewise continuous trial function, Galerkin's finite element formulation, variational formulation of the problem, Ritz method

Finite element solution to beam problem and plane frame, plates and shells, introduction to non-linear analysis, convergence criteria, stress stiffening, geometric and material non-linearity

Solution of eigen problems, transformation methods, Jacobi method, vector iteration methods, subspace iteration method, direct integration methods for dynamic analysis, Newmark method, mode superposition, change of basis to modal generalized displacements, effect of damping

Crack tip element, reduced integration, incompatible modes, shear locking and hour glass phenomenon, modelling of gap and contacts, adaptive mesh refinement

Introduction, Study State Heat transfer-1D and 2D Heat Conduction, Governing differential equation, Boundary Condition, Formulation of element

Type and size of element, mapped elements, quality checks-[aspect ratio, warp angle, skew, Jacobean, distortion, stretch, included angle, taper], boundary conditions, interpretation of results and design modification.

Term Work

The term work shall consist of record of any three from 1 to 4 and three from 5 to 8 assignments of problems based on the following topics:

1. Matlab program for axial bar subjected to temperature and axial forces
2. Matlab program for truss subjected to plane forces
3. Matlab program for beams subjected to transverse forces and moments
4. Matlab program for frames subjected to transverse forces and moments
5. Stress and deflection analysis of two dimensional truss using finite element Package
6. Stress and deflection analysis of any Mechanical component consisting of 2-D elements using finite element package
7. Stress and deflection analysis of any Mechanical component consisting of 3-D elements using finite element package
8. Modal analysis of any mechanical component

COURSE OUTCOMES: At the end of the course, the student shall be able to:

1. Understand the concept of finite element method for solving machine design problems
2. Formulate and solve manually problems in 1-D structural systems involving bars, trusses, beams and frames.
3. Develop 2-D FE formulations involving triangular, quadrilateral elements and higher order elements.
4. Apply the knowledge of FEM for stress analysis, model analysis, heat transfer analysis and flow analysis.
5. Develop algorithms and write FE code for solving simple design problems and understand the use of commercial packages for complex problems.

References

1. Zienkiewicz O. C., Taylor, R. I., The Finite Element Method, Butterworth-Heinemann, Fifth Edition 2000.
2. Akin J.E., Finite Element Analysis with Error Estimators, Elsevier, 2005.
3. Cook R. D., Finite Element Modeling for Stress Analysis, John Wiley & Sons Inc, 1995.
4. Liu G.R. and Quek S. S., The Finite Element Method – A Practical Course, Butterworth-Heinemann, 2003.
5. Kwon Y. W., Bang H., Finite Element Method using MATLAB, CRC Press, 1997.
6. Asghar Bhatti, Fundamental Finite Element Analysis and Applications, John Wiley & Sons Inc, 2005
7. Chandrupatla T.R. and Belegunda A.D., Introduction to Finite Elements in Engineering, Prentice Hall of India.

Mathematical Modeling and Analysis

System, environment and variables, the state of a system, mathematical models of continuous line linear lumped parameter time invariant systems, discrete time systems, linear approximation of non-linear systems, topological models of system, block diagram representation, signal flow graph, Mason's rule

The principles of conservation and continuity,physical laws,mechanical systems, electrical and electro mechanical systems, fluid systems, thermal systems

The linear graph approach, linear graph terminology, formulation of system equations, systems with multi terminal components,linear graph models: skeletal structures, mass transfer processes

Discrete signal models, discrete time-convolution, response of linear discrete time systems, continuous (analogue) signal models, continuous time convolution, response of linear continuous time state equation - discrete time systems, computation of state transition matrix by canonical transformation, computation of state transition matrix by technique based on Caley-Hamilton theorem, the solution of state equation-continuous time systems

Numerical method for solution of continuous time state, ordinary differential equations: explicit and implicit techniques, adaptive step size control, adaptive RK method, numerical methods for partial differential equations

Application of Laplace transforms to differential equations, stability in s domain, linear system, Laplace transform analysis of causal periodic input to linear systems, relationship of the Z transform to the Fourier and Laplace transforms

Fourier spectra of power signals, Fourier transform of periodic functions- Fourier series, Fourier analysis of sampled signals, modulation, discrete Fourier transforms

The inverse Z-transform, Z-transform analysis of linear discrete time systems, nature of response of linear discrete-time systems, computation system, de-convolution

Multi resolution analysis and construction of wavelets, representation of functions by wavelets, the characterization of MRA wavelets

Introduction to simulation: digital and analogue simulation, analytic and Monte Carlo simulation, stochastic and deterministic simulation, random and pseudo random number generation, designing a simulation experiment, simulating basic stochastic models, simulator technology, applications

References

1. Nicola Bellomo & Luigi Preziosi, Modeling Mathematical Methods & Scientific Computations, 1995, CRC Press.
2. I.J. Nagarath & M. Gopal, Systems Modeling & Analysis, Tata McGraw Hill, New Delhi.
3. Jan Willen Polderman, Jan C. Willems, Introduction to Mathematical Systems Theory-Abehavioural approach, 1998, Springer.
4. J.L. Shearer, A.T. Murphy, H.H. Richardson, Introduction to System Dynamics, 1971,Addison & Wesley.
5. T.H. Glisson, Introduction to System Analysis, 1987, McGraw Hill.
6. W.J. Palm, Modeling Analysis and Control of Dynamic Systems, 2nd Ed., 1999, JohnWiley.
7. Ernest O Doebelin, System Modeling and Response, theoretical and experimentalapproaches, 1980, Wiley.
8. Gray M. Sandquist, Introduction to System Science.
9. David K. Cheng, Analysis of Linear Systems.
10. James B. Reswick, Charles K Taff, Introduction to Dynamic Systems.
11. Robert L. Woods, Kent L. Lawrence, Modeling & Simulation of dynamic system.
12. Robert A. Gabel & Richard A. Roberts, Signals and Linear Systems.
13. Eugenio Hernandez, Guido Weiss, A First Course on Wavelets, 1996, CRC Press.
14. Alan V Oppenheim & Ronald W. Schafer, Digital Sigal Processing, Prentice Hall of India, Pvt.Ltd.
15. Richard E Blahut, Fast Algorithms for Digital Signal Processing, 1985, Addison-WesleyPublishing Co.
16. Dougllao F Elliott, K Ramamohan Rao, Fast Transforms Algorithms, Analysis and Applications, 1982, Academic Press Inc., Chapters 1, 2 & 3.

Instrumentation & Experimental Techniques

Basic concepts of measurement methods and planning and documenting experiments, typical sensors, transducers, and measurements system behavior, Data sampling and computerized data acquisition systems, statistical methods and uncertainty analysis applied to data reduction, laboratory experiments with measurement of selected material properties and solid mechanical and fluid/thermal quantities.

Static and dynamic characteristics of signals, review of electrical devices and signal processing, computerized data acquisition, temperature measurements, pressure and velocity measurements, fluid flow measurements, strain measurements, displacements and motion measurements.

Dynamics measurements and signal analysis.

Measurement of derived quantities, torque, power, thermo physical properties, radiation and surface properties, analytical methods and pollution monitoring, mass spectrometry, chromatography, spectroscopy.

Optical Methods - Optical Microscopy, Confocal Microscopy, X-ray Microscopy, UV/VIS Spectrometry, Infrared Spectrometry (FTIR), Terahertz Spectroscopy (THz), Raman Spectroscopy, Surface Enhanced Raman Spectroscopy (SERS).

Electron Microscopy - The Electron Optical System, Electron Range, Scanning electron microscopy (SEM), Transmission electron microscopy (TEM)

X-ray Spectroscopy and diffraction, Atomic force microscope (AFM), Scanning tunneling microscopy (STM), Scanning Near-field optical microscopy (SNOM)

References

1. E.O. Doeblin, Measurement Systems - Application and Design, McGraw-Hill.
2. J.P. Holman, Experimental Methods for Engineers, McGraw-Hill.
3. J. W. Dally, W. F. Riley, and K. G. McConnell, Instrumentation for Engineering Measurements, John Wiley & Sons.

Vehicle Dynamics

Tire forces and moments, rolling resistance of tires, tractive (braking) effort and longitudinal slip (skid), cornering properties of tires, slip angle and cornering force, slip angle and aligning torque, camber and camber thrust, characterization of cornering behavior of tires, performance of tires on wet surfaces, ride properties of tires

Equation of motion and maximum tractive effort, aerodynamic forces and moments, vehicle power plant and transmission characteristics, power plant characteristics, transmission characteristics, prediction of vehicle performance, acceleration time and distance, gradability, operating fuel economy, engine and transmission matching, braking performance, braking characteristics of a two-axle vehicle, braking efficiency and stopping distance, braking characteristics of a tractor-semitrailer, antilock brake systems, traction control systems.

Steering geometry, steady-state handling characteristics of a two-axle, vehicle, steady-state response to steering input, testing of handling characteristics, transient response characteristics, directional stability, criteria for directional stability, vehicle stability control, steady-state handling characteristics of a tractor-semitrailer.

Human response to vibration, vehicle ride models, two-degree-of-freedom vehicle model for sprung and unsprung mass, numerical methods for determining the response of a quarter-car model to irregular surface profile excitation, two-degree-of-freedom vehicle model for pitch and bounce, introduction to random vibration, surface elevation profile as a random function frequency response function, evaluation of vehicle vibration in relation to the ride comfort criterion, active and semi-active suspensions.

Motion resistance of a track, tractive effort and slip of a track, simplified analysis of the kinetics of skid-steering, kinematics of skid-steering, skid-steering at high speeds, a general theory for skid-steering on firm ground, shear displacement on the track-ground interface, kinetics in a steady-state turning maneuver, experimental substantiation, coefficient of lateral resistance, power consumption of skid-steering, steering mechanisms for tracked vehicles, clutch and brake steering system, controlled differential steering system, planetary gear steering system, articulated steering.

The multibody systems approach to vehicle dynamics

References

1. Michael Blundell & Damian Harty, The Multibody Systems Approach to Vehicle Dynamics, Elsevier
2. Thomas D. Gillespie, Fundamentals of Vehicle Dynamics, SAE
3. Ulrich W. Seiffert, Hans Hermann Braess, Handbook of Automotive Engineering, SAE
4. G. Genta, Motor Vehicle Dynamics: Modeling and Simulation, World Scientific
5. Homer Rahnejat, Multi-body dynamics: vehicles, machines and mechanisms, Professional Engineering Publications.
6. Homer Rahnejat, Multi-body dynamics: monitoring and simulation techniques-II, Steve Rothberg, Professional Engineering Publications
7. Homer Rahnejat, Multi-body dynamics: monitoring and simulation techniques-III, Steve Rothberg, Professional Engineering Publications
8. JY Wong, Theory of Ground vehicles, Wiley.

Engineering Fracture Mechanics

Review of - Mechanical properties of solid materials, theory of elasticity stress and strain, plane stress, plane strain, stress function, theory of plasticity, yield stress, yield conditions (Mises & Tresca)

Macroscopic failure mode, ideal fracture strength, energy release rate, fracture Modes

Griffith criterion, Irwin's fracture criterion, stress intensity approach, stress intensity factor, crack tip plasticity, crack opening displacement, plastic constraint

Methods for evaluating fracture toughness
Numerical Methods
a. Finite Elements (FE)
b. Finite Differences (FD)
c. Boundary Integral Equations (BIE)
Experimental Methods
a. Compliance Method
b. Photoelasticity
c. Interferometry and Holography

Experimental evaluation of Fracture toughness: Plane strain fracture toughness, J– Integral, CTOD

Fatigue: S-N diagram, fatigue limit, fatigue crack growth rate, Paris law

Creep mechanics: creep deformation, creep strength, creep-fatigue interaction

References

1. Anderson T.L., Fracture Mechanics, 2nd Edition, CRC Press, 1995
2. Hertzberg, R. W. Deformation and Fracture Mechanics of Engineering Materials. 4thed. John Wiley & Sons, Inc., 1996.
3. ASTM standard E 1820

Advanced Machine Design

Engineering statistics, analysis of variance (ANOVA), factorial design and regression analysis, reliability theory, design for reliability, Hazard analysis, fault tree analysis

Fatigue and creep, introduction, fatigue strength, factors affecting fatigue behavior, influence of super imposed static stress, cumulative fatigue damage, fatigue under complex stresses, fatigue strength after over stresses, true stress and true strength, mechanism of creep of material at high temperature, exponential creep law, hyperbolic sine creep law, stress relaxation, bending etc.

Optimization, introduction, multivariable search methods, linear & geometric programming, structural and shape optimization and simplex method

Composite materials, composite materials and structures, classical lamination theory, elastic stress analysis of composite material, fatigue strength improvement techniques, stresses, stress concentration around cutouts in composite laminates, stability of composite laminate plates and shells, hybrid materials, applications

Design for Materials and Process, Design for brittle fracture, design for fatigue failure, design for different machining process, assembly & safety etc.

Design of Mechanical components, a) gear design: involute gears, tooth thickness, interference, undercutting, rackshift etc., profile modification, S and So spur, helical gears etc. b) spring design: vibration and surging of helical springs, helical springs for maximum space efficiency, analysis of Belleville springs, ring spring, volute spring & rubber springs, design for spring suspension, c) design of miscellaneous components (to be detailed) cam shaft with valve opening mechanism, piston, cylinder, connecting rod etc.

LAB PRACTICE
1 One complete design project considering all above concepts
2 Two assignments (Gear & spring)

References

1. M.F. Spotts, Mechanical Design Analysis
2. Robert Norton, Machine Design
3. D.W. Dudley, Practical Gear design
4. R.C. Jhonson, Optimum design
5. A.M. Wahl, Mechanical Springs
6. D. Hull and T.W. Clyne, An introduction to composite materials

Analysis and Synthesis of Mechanisms

Basic concepts: definitions and assumptions, planar and spatial mechanisms, kinematic pairs, degree of freedom

Kinematic analysis of complex mechanisms: velocity-acceleration analysis of complex mechanisms by the normal acceleration and auxiliary point methods

Dynamic analysis of planar mechanisms: inertia forces in linkages, kinetostatic analysis of mechanisms by matrix method. analysis of elastic mechanisms, beam element, displacement fields for beam element, element mass and stiffness matrices, system matrices, elastic linkage model, equations of motion

Curvature theory: fixed and moving centrodes, inflection circle, Euler- Savy equation, Bobillier constructions, cubic of stationary curvature, ball's point, applications in dwell mechanisms

Graphical synthesis of planar mechanisms: type, number and dimensional synthesis, function generation, path generation and rigid body guidance problems, accuracy (precision) points, Chebychev spacing, types of errors, graphical synthesis for function generation and rigid body guidance with two, three and four accuracy points using pole method, center point and circle point curves, Bermester points, synthesis for five accuracy points, branch and order defects, synthesis for path generation

Analytical synthesis of planar mechanisms:- analytical synthesis of four-bar and slider- crank mechanism, Freudenstein's equation, synthesis for four accuracy points, compatibility condition, synthesis of four-bar for prescribed angular velocities and accelerations using complex numbers. complex numbers method of synthesis, the dyad, center point and circle point circles, ground pivot specifications, three accuracy point synthesis using dyad method, Robert Chebychev theorem, cognates kinematic analysis of

Spatial mechanisms: Denavit-Hartenberg parameters, matrix method of analysis of spatial mechanisms

References

1. A. Ghosh and A.K.Mallik, Theory of Machines and Mechanisms, Affiliated East-West Press.
2. R. S. Hartenberg and J. Denavit, Kinematic Synthesis of Linkages, McGraw-Hill.
3. A. G. Erdman and G. N. Sandor, Advanced Mechanism Design - Analysis and Synthesis (Vol.1 and 2), Prentice Hall of India.
4. J. E. Shigley and J. J. Uicker, Theory of Machines and Mechanisms, 2nd Ed.,McGraw-Hill.
5. Robert L. Norton, Design of Machinery: An Introduction to the Synthesis and Analysis ofMechanisms and Machines, Tata McGraw-Hill, 3rd Edition.
6. A.S. Hall, Kinematics and Linkage Design, Prentice Hall of India

Term Work:

The term work comprises of assignments on the following topics.

1. Complex Mechanism Analysis.
2. Dynamic Analysis.
3. Graphical and Analytical Synthesis.
4. Curvature Theory.

Use of software such as 'ADAMS' and 'Working Model' is recommended

Advanced Thermodynamics

Equation of state, state postulate for simple system and equation of state, ideal gas equation, deviation from ideal gas, equation of state for real gases, generalized compressibility chart, law of corresponding states

Properties of pure substances, phase change process of pure substances, PVT surface, P-V & T - t diagrams, use of steam tables and charts in common use

Laws of thermodynamics, 2nd law analysis for engineering systems, entropy flow & entropy generation, increase of entropy principle, entropy change of pure sub, t-ds relations, entropy generation, thermo electricity, Onsager equation, exergy analysis of thermal systems, decrease of exergy principle and exergy destruction

Thermodynamic property relations, partial differentials, Maxwell relations, Clapeyron equation, general relations for du, dh, ds, and Cv and Cp, Joule Thomson coefficient, Δh, Δu, Δs of real gases

Chemical thermodynamics, chemical reaction - fuels and combustion, enthalpy of formation and enthalpy of combustion, first law analysis of reacting systems, adiabatic flame temperature
Chemical and phase equilibrium - criterion for chemical equilibrium, equilibrium constant for ideal gas mixtures, some remarks about kp of ideal-gas mixtures, fugacity and activity, simultaneous relations, variation of kp with temperature, phase equilibrium, Gibb's phase rule, third law of thermodynamics, Nerst heat theorem and heat death of universe

Gas mixtures – mass & mole fractions, Dalton's law of partial pressure, Amagat's law, Kay's rule

Statistical thermodynamics- fundamentals, equilibrium distribution, significance of Lagrangian multipliers, partition function for canonical ensemble, partition function for an ideal monatomic gas, equipartition of energy, Bose Einstein statistics, Fermi- Dirac statistics

Exercises/ assignments for laboratory practice:

1. Computer aided energy analysis of steady flow cyclic system
2. Study of mixture of gases, gas and vapour, estimation of properties and preparation of Charts
3. Analysis of ideal gas system using statistical thermodynamic techniques
4. Study of behavior of pure substance with change in pressure and temperature
5. Preparation of computer program to study the effect of percentage of theoretical on adiabatic flame temperature and equilibrium composition for a hydrocarbon fuel (program to be run for variable input data)

References

1. Cengel, Thermodynamics, TMH
2. Howell & Dedcius: Fundamentals of engineering Thermodynamics, McGraw Hill,Inc, USA
3. Van Wylen & Sontag: thermodynamics, John Wiley & Sons, Inc.,USA

4. Holman, Thermodynamics, 4th edition, McGraw Hill
5. Zimmansky & Dittman, Heat and Thermodynamics, 7th edition, TMH
6. Rao, Y.V.C., Postulational and Stastistical thermodynamics, Allied Pub. Inc.
7. Jones and Hawkings: engineering Thermodynamics, john Wiley & Sons, Inc. USA
8. Faires V. M. and Simmag: Thermodynamics. McMillan Pub. Co. Inc. USA
9. Turns, Thermodynamics- Concepts and Applications, Cambridge University Press
10. Wark, Advanced Thermodynamics, McGraw Hill
11. Nag P.K., Basic & Applied Thermodynamics, TMH, New Delhi.
12. Jones & Dugan, Advanced Thermodynamics, Prentice Hall Int.
13. Bejan, Advanced Thermodynamics, John Wiley, Inc.

Advanced Heat Transfer

Overview of the subject of heat transfer with orientation to applications, the various boundary conditions, analytical solutions for temperature distribution, concept of thermal resistance, contact resistance, problems related to anisotropic materials, numerical methods for fin analysis

Transient conduction: lumped capacitance and its validity, general lumped capacitance analysis, spatial effects. Problems related with conventional geometries, principle of fluid flow and convective heat transfer

Concept of velocity and thermal boundary layers: laminar and turbulent flow, Navier-stokes equations and convection equation, boundary layer approximations and special conditions, boundary layer similarity, the normalized convection transfer equations, dimensionless parameters & physical significance, Reynolds analogy, Chilton-Colburn analogy

Forced convection (external flow) empirical method, flat plate in parallel flow, the Blasius solution(highlights only), local and average Nusselt number calculations, mixed boundary layer considerations

Forced convection (internal flow) laminar flow in a pipe, friction factor, thermal considerations, mean temperature, constant heat flux and constant wall temperature, thermal analysis and convection correlations for laminar flow in circular tubes, evaluation of Nusselt number, Marcos and Bergles correlation

Convection correlations: turbulent flow in circular tubes, for non-circular tubes, heat transfer enhancement, passive, active and compound techniques

Free convection: physical considerations, governing equations, similarity considerations. Laminar free convection on a vertical surface, effects of turbulence, empirical correlations for external free convection flows for various geometries and orientations, free convection within parallel plate channels, empirical correlations for enclosures, mixed convection, boiling and condensation boiling modes, the boiling curve, modes of pool boiling, correlations

Forced convection boiling, two phase flow, condensation: physical mechanisms, laminar film condensation on a vertical plate, turbulent film condensation, film condensation on radial systems, film condensation in horizontal tubes, on banks of tubes, dropwise condensation correlations

Thermal radiation fundamental concepts, radiation intensity: relation to emission, irradiation and radiosity, black body radiation and associated laws, spherical and hemispherical properties, environmental radiation, radiation exchange between surfaces, the view factor, black and gray surfaces, network method, reradiating surfaces, multimode heat transfer, gaseous emission and absorption

Cooling of electronic equipment introduction: manufacturing, chip carrier, PCN’s, the enclosure, cooling load of electronic equipment, thermal environment, electronics cooling in different applications, conduction cooling, conduction in chip carriers and PCB’s. Heat frames, air cooling, cooling of PC’s, liquid cooling, immersion cooling, ablative , transpiration and high speed cooling

Assignments:

1. Fluidized bed combustion.
2. Heat pipes
3. Numerical method in heat conduction & convection.
4. Combined heat transfer.
5. Passive heat transfer augmentation techniques.
6. Electronic cooling
7. One problem on network method (Radiation).
8. Heat transfer during melting and solidification.

References

1. Incropera and Dewitt, Fundamentals of heat and mass transfer, John Wileyand sons.
2. Yunus Cengel, Heat transfer - a practical application, Tata McGraw Hill.
3. M.N. Ozisik, Heat transfer a basic approach, McGraw Hill Int.
4. A Bejan, Convective heat transfer, John Wiley and sons.
5. J.P. Holman- Heat transfer, McGraw Hill, Int.
6. S.P. Sukhatme, Heat transfer, University Press

Advanced Fluid Mechanics

Governing equations: mass conservation in differential and integral forms, flow kinematics, and momentum equation: substantial derivative, differential and integral form, stress tensor, stress strain relations, ideal fluid flow concepts

Navier-Stokes equations: special forms: Euler equations, Bernoulli equation, stream function, vorticity

Exact solutions: fully developed flow in channel, pipe, flow between concentric rotating cylinders, Couette flow, stokes first problem (unsteady flow), creeping flow past a sphere, cylinder

Boundary layers: boundary layer assumptions, equations, flow over a flat plate, similarity (Blasius) solution, Falkner-Skan equation, momentum integral method, external flows: drag, lift, flow separation

Turbulent flow: introduction to hydrodynamic stability, characteristics of turbulence, governing equations, turbulent boundary layer, algebraic models (Prandtl's mixing length), velocity profile over a flat plate and in pipes.

Turbulent shear flows: equations for free shear layers: mixing layer, plane and axisymmetric jet, wake, turbulent energy equation, two equation model (k-epsilon), large eddy simulation, various turbulent models

Compressible flow: one-dimensional flow: speed of sound, variable cross-section flow, converging diverging nozzle, effect of friction and heat transfer, normal shock relations, introduction to oblique shocks, 2-dimensional flows(subsonic and supersonic) past slender bodies, compressible boundary layers.

Lab Experiments:

1. Flow over a cylinder/sphere at different Re. pressure variation over the body and drag estimation
2. Flow past an aerofoil: pressure measurements, calculation of lift
3. Flow through a converging-diverging nozzle: subsonic and supersonic flows
4. Friction factor determination: incompressible flow through pipes/ducts of variable cross-section
5. Laminar/Turbulent boundary layer over a flat plate.

Assignments:

1. Numerical simulation of flow through a c-d nozzle
2. Testing of turbulence models
3. Blasius / Falkner-Skan solutions.

References

1. G. Biswas and K. Muralidhar, Advanced Fluid Mechanics
2. F. M. White, Viscous Fluid Flow
3. H. Schlichting, Boundary Layer Theory
4. Cengel, Fluid Mechanics, Tata McGraw Hill

Computational Fluid Dynamics

Introduction to CFD, historical background, impact of CFD

The governing equations of fluid dynamics, derivation, discussion of physical meanings and presentation of forms particularly suitable to CFD

Mathematical behavior of partial differential equations: impact on CFD

Basic aspects of discretization: introduction to finite difference, finite elements and finite volume methods, detailed treatment of finite difference method, explicit and implicit methods, errors and stability analysis

Grids with appropriate transformations, adaptive grids and unstructured meshes

A Few CFD Techniques
The Lax-Wendroff Technique, MacCormack's technique, space marching, relaxation technique, numerical dissipation and dispersion, artificial viscosity, the ADI technique, pressure correction technique: application to incompressible viscous flow, the SIMPLE algorithm

Numerical solutions of quasi-one-dimensional nozzle flows

Numerical solution of a 2D supersonic flow, Prandtl-Meyer expansion wave

Incompressible Couette flow, solution by implicit method and the pressure correction method

Supersonic flow over a flat plate, numerical solution by solving complete Navier Stokes equation

References

1. John D. Anderson Jr, "Computational Fluid Dynamics-The Basics withApplications", Mcgraw Hill. Inc.,
2. Fletcher C.A.J. "Computational Techniques for Fluid Dynamics", Volumes I and II,Springer, Second Edition [2000]
3. C. Hirsch, "Numerical Computation of Internal and External Flows", Volumes I andII, John Wiley & Sons [2001]

Advanced Gas Dynamics

Review of Elementary Principles, Mathematical Concepts, Thermodynamic Concepts for Control Mass Analysis

Control Volume Analysis, Flow Dimensionality and Average Velocity, Transformation of Material Derivative to a Control Volume Approach, Conservation of Mass, Conservation of Energy, Comments on Entropy, Pressure-Energy Equation, The Stagnation Concept, Stagnation Pressure-Energy Equation, Consequences of Constant Density

Introduction to Compressible Flow, Sonic Velocity and Mach Number, Wave Propagation, Equations for Perfect Gases in terms of Mach Number, h-s and T-s Diagrams

Varying Area Adiabatic Flow, General Fluid Flow without Losses, Perfect Gas Flow with Losses, The * reference concept, Isentropic Table, Nozzle operation and performance, Diffuser performance

Standing Normal Shocks, Shock analysis for a general fluid, Working equations for perfect gases, Normal Shock table, Shocks in Nozzles, Supersonic wind tunnel

Moving and Oblique Shocks, Normal velocity superposition: Moving normal shocks, tangential velocity superposition: Oblique shocks, oblique shock analysis of perfect gas, oblique shock table and charts, Boundary condition of flow direction, Boundary condition of pressure equilibrium, Conical shocks

Prandtl-Meyer Flow, Argument for isentropic turning flow, Analysis of Prandtl–Meyer flow, Prandtl- Meyer function, overexpanded and underexpanded nozzles, supersonic airfoils

Fanno Flow, Analysis for a General fluid, Working equations for perfect gases, reference state and Fanno table, applications, correlation with shocks, friction chocking

Rayleigh Flow, Analysis for a general fluid, Working equations for perfect gases, reference state and Rayleigh table, applications, correlation with shocks, thermal chocking due to heating

Real Gas Effects, Behavior of real gases, Equations of states and compressibility factors, semiperfect gas behavior

References

1. Zucker R. D. and Biblarz Oscar, Introduction to Gas Dynamics, JohnWiley and Sons. Inc., Second Edition, 2002
2. A. H. Shapiro,Dynamics and Thermodynamics of Compressible FluidFlow, MIT Press.
3. Zucrow, Gas Dynamics, Vol I

ADVANCED AIR CONDITIONING, HEATING AND VENTILATION

Applied Psychrometry, Psychrometric processes using chart

Load Estimation: solar heat gain, study of various sources of the internal and external heat gains, heat losses, etc. Methods of heat load calculations: Equivalent Temperature Difference Method, Cooling Load Temperature Difference, and Radiance Method, RSHF, GSHF, ESHF, etc. Inside and outside design conditions

Air Distribution: Fundamentals of air flow in ducts, pressure drop calculations, design ducts by velocity reduction method, equal friction method and static regain method, duct materials and properties, insulating materials, types of grills, diffusers, wall registers, etc. VAV

Sound Control: Definitions of various terms like level, pitch, attenuation, frequency, sources of noise in air conditioning plants, design procedure for noise prevention, noise and vibration study and elimination techniques (description only).

Ventilation and Infiltration: Requirement of ventilation air, various sources of infiltration air, ventilation and infiltration as a part of cooling load. Fans and Blowers: Types, performance characteristics, series and parallel arrangement, selection procedure

Direct and Indirect Evaporative Cooling: Basic psychometric of evaporative cooling, types of evaporative coolers, design calculations, indirect evaporative cooling for tropical countries

Air Conditioning Equipments and Controls: Chillers, Condensing units, Cooling coils, bypass factors, humidifiers, dehumidifiers, various types of filters, air washers, thermostat, humidistat, cycling and sequence controls, modern control of parity, odour and bacteria, Air filtration- Study of different types of filters, BMS applications. Cooling Towers

Air conditioning systems: Classification, design of central and unitary systems, typical air conditioning systems such as automobile, air plane, ships, railway coach air-conditioning, warm air system, hot water systems, heat pump, clean rooms (descriptive treatments only). VRF

Standards and Codes: ASHRAE/ARI, BIS standards study and interpretation, ECBC, NBC codes
(* Question Paper- 50% to 60% of maximum marks are kept for the questions
asked on System Design and not any theory.)

Term Work

1. Design Project for system selection, load estimation, duct design, equipmentselection, Control systems, cost estimation, lay out diagrams (line sketches) for anyone application from: Hospital, Hotel, Auditorium, Computer lab, Operation Theateretc.
2. Draw Psychrometric chart for a nonstandard Pressure

References

1. ASHRAE Handbooks
2. ISHRAE Handbook.
3. Handbook of Air Conditioning System Design, Carrier Incorporation, McGrawHill Book Co., USA.
4. Trane air conditioning manual,
5. Refrigeration and Air conditioning, ARI Prentice Hall, New Delhi.
6. Norman C. Harris, Modern air conditioning
7. Jones W. P., Air conditioning Engineering, Edward Arnold Publishers Ltd,London, 1984.

8. Jones W. P., Air conditioning Engineering - Applications, Edward ArnoldPublishers Ltd, London, 1984
9. Hainer R. W., Control System for Heating, Ventilation and Air conditioning, VanNastrand Reinhold Co., New York, 1984.
10. C P Arora, Refrigeration and Air conditioning, Tata McGraw Hill Publication,New Delhi.
11. McQuiston, Faye, Parker, Jerald, Spitler, Jeffrey, 2000, Heating, Ventilating andAir Conditioning-Analysis and Design, 5th ed. John Wiley & Sons

Elective - Internal Combustion Engines

Measurement & Testing: Introduction, engine performance parameters, measurement and testing, engine operating characteristics, performance maps

Engine Materials: Various engine components, cylinder head, spark plug, gaskets, cylinder block, piston, piston rings, gudgeon pin, connecting rod, crankshaft, bearings, crankcase, fuel injector

Engine Design: Preliminary analysis, cylinder number, size and arrangement, experimental development
Electronic Injection System: Gasoline injection, EFI system, MPFI system, electronic control system, injection timing, electronic diesel injection system and control

Engine Emissions & Control: Air pollution due to IC engines, norms, engine emissions, HC, CO, NOx, particulates, other emissions, emission control methods, exhaust gas recirculation, modern methods, crankcase blow by

Simulation Technique: Application of simulation technique for engine tuning, engine selection parameters, recent trends in IC engines

Experiments (any four)
1. Performance trial on 4-cylinder 4-stroke petrol engine
2. Performance trial on diesel engine
3. Emission measurements by using gas analyzer and smoke meter
4. Case study for engine selection
5. Visit to research organization

References

1. Charles Fayette Taylor, The Internal Combustion Engine- Theory and Practice, Vol. I & II, The MIT Press
2. V Ganesan, Internal Combustion Engines, 2nd edition, Tata McGraw Hill
3. Jack Erjavec, Automotive Technology, 3rd edition, Delmar Thomson Learning
4. Gordon P Blair, Design and Simulation of four stroke engines, SAE International

5. Gasoline Engine Management, Bosch handbook,2nd edition, ProfessionalEngineering Publication
6. C.R. Ferguson & A.R. Kirkpatrick, Internal Combustion Engines, Tata McGraw Hill,2001

Advanced Physical and Mechanical Metallurgy

Microstructure & Properties: solidification and solidification structures, interfaces, crystallographic texture, residual stress, structure-property relations.

Plasticity and work hardening: fundamentals, stress-strain behavior, fracture, creep & deformation mechanisms. Recovery, recrystallization, grain growth

Phase transformation: thermodynamic basics, nucleation and growth, spinoidal decomposition, martensitic transformations

References

1. T.H. Courtney, Mechanical Behavior of Materials, McGraw-Hill, 2nd Ed., 2000.
2. R.W. Cahn, P. Haasen and E.J. Kramer, (Eds.), Materials Science and Technology: A Comprehensive Treatment, VCH, Weinheim, Germany, 1993.
3. R.E. Smallman and A.H.W. Ngan, Physical Metallurgy & Advanced Materials, 7th Ed., Elsevier, 2007.
4. J.W. Martin, R.D. Doherty and B. Cantor, Stability of Microstructures in Metallic Systems, 2nd Ed., Cambridge University Press, UK, 1997.
5. D.A. Porter. and K.E. Easterling, Phase Transformations in Metals and Alloys, Van Nostrand Reinhold, UK, 1986.
6. C.R. Calladine, Plasticity for Engineers – Theory and Applications, Horwood, Chichester, England, 2000.
7. B. Verlinden, J. Driver, I. Samajdar, R.D. Doherty, Thermo-Mechanical Processing of Metallic Materials, Pergamon Materials Series, Series Ed. R.W. Cahn, Elsevier, Amsterdam, 2007.

Industrial Automation

Automation strategy, Plant wide control systems and Automation strategy, Evolution of instrumentation and control, Role of automation in industry, Benefits of automation, Introduction of automation tools PLC, DCS, SCADA, Hybrid DCS/PLC, Automation strategy evolution, control system audit, performance criteria, development of user requirement specification (URS) for automation, Functional design specifications (FDS) for automation tools

PLC, Advance applications of PLC, PLC programming methods as per IEC 61131 , PLC applications for batch process and Process using SEC, Analog control using PLC, PLC interfacing to SCADA/DCS using communications links ,Industrial Ethernet

Distributed control systems

Distributed control systems: DCS introduction, functions, advantages and limitations, DCS as an automation tool to support Enterprise resource planning, DCS component block diagram, Architecture of different makes, DCS Specifications, Latest trends and developments, performance criteria for DCS and other automation tools. SCADA specifications for different real time applications

Numerical control machines, fundamentals of numerical control including system concept, Design features of NC and CNC machines, Devices: drivers, servomechanism, tooling specifications, feedback components, positioning control, &countering pattern

CNC, CNC concepts, principle of operation of CNC, steps in manufacturing, construction features including drivers and structures, Advantages and limitations of CNC, axis of CNC machines, CNC programming using G codes, use of subroutines, computer aided part programming using APT programming, 2D and 3D integration and programming from CAD models and data banks. Multiple channel concepts, PLC selection, CNC selection guidelines Absolute and incremental encoders, Interface

Sourcing, sinking of PNP/ NPN digital input, outputs, PLC scan, synchronous & asynchronous events, fast acting I/O modules, sequence logic, step logic, FCs, FBs concept

Laboratory Practice: Perform any four practical from the following list of practical

1. Development of Ladder diagram/ Programming PLC for level control,position control or any application.
2. NC/ CNC programming.
3. PLC/ CNC interface
4. Low cost PLC based automation.
5. Multiple PLC/ MMI/Servo system.

Perform any two assignments from the following list of assignments.

1. Design of robotic arm as Mechatronics case study.
2. Design of coin counter as Mechatronics case study.
3. Design of wending machine as Mechatronics case study.
4. Design of strain gauge based weighing machine as Mechatronics case study.
5. Design of rotary optical encoder as Mechatronics case study.
6. Design of skip control of CD player as Mechatronics case study.

References

1. The management of control system Justification & Technical auditing,N E Britannica, ISA
2. S.K.Singh, Computer Aided process control, Prentice Hall of India
3. Webb & Ries, Programmable Logic controllers, Prentice Hall of India
4. Garry Dunning, Introduction of PLC, Thomas learning
5. Distributed control systems for Industrial Automation Popovik Bhatkar,Prentice Hall of India
6. Krishna Kant, Computer based process control, Prentice Hall of India
7. Ibrahim Zeid, CAD/ CAM- Theory and Practice
8. Ramamurthy V, Computer aided mechanical design & analysis

Microcontrollers

Introduction to 8 bit architecture, memory and I/O interfacing, Introduction to software and hardware tools (Cross assembler, Logic analyzer, Emulator, Simulator)

8051 architecture, comparison with microprocessor, Pin diagram, clock and oscillator, flags, PSW, Stack, Internal Memory, External Memory, Idle mode, Power down mode, SFR counter, timer, timer mode, serial I/O, and interrupt structure

Programming, Instruction set, addressing mode and programming of 8051. Interfacing to external world, external RAM and ROM, Display (LED/LCD) and key board, ADC and DAC, memory Interfacing, Stepper motor, I^2C compatible,PIC Controllers

Architecture of PIC microcontrollers, features, interfacing of I/O devices with PIC controllers. PIC 16c6x, 16c7x. PIC memory organization

Introduction to ARM controllers, Comparison between RISC & CISC processor, Versions & variants of ARM processor,Register model of ARM processor, Modes of operation, Applications of ARM processor

Buses and protocols, RS 232 C, RS485, I2C, SPI, Modbus, Derivatives of microcontroller, Conceptual Study of various derivatives of 8051 microcontroller such as RD, OTP, AVR, containing PWM, RTC, Timer, EEPROM, in system programming

Laboratory Practice: Perform any four practicals from the following list of practicals
(1) Interfacing of keyboard and display.
(2) Interfacing of stepper motor and ADC/DAC.
(3) I^2C Interfacing
(4) RS-232 Interfacing
(5) Interfacing of displays and peripherals to ARM processors.
(6) Covert a proven Rubic cube algorithm into a higher level language, cross compile and use the micro controller to guide a robot to solve the rubic cube.
(7) Implement a row column matrix of optical sensors connected with microcontroller. Implement a user friendly storage system for an assembly station where assembly operator will pick up assembly components from storage in desired sequence only (sequence on microcontroller, feedback from optical row column matrix, flashing lamps for every location for user friendly implementation.)
(8) Implement a simple PLC on a microcontroller kit.

References

1. Kennith Ayala, 8051 Microcontroller, Thomas Learning.
2. Predko, Programming and customizing 8051 microcontroller, TMH.
3. Peatman, Programming PIC microcontrollers, Pearson Education

4. A.V.Deshmukh, Microcontrollers Theory & Applications, McGraw Hill
5. Rajkamal, Microcontrollers, Architecture &Programming, Pearson Education
6. M.A.Mazidi &J.G.Mazidi, The 8051 Microcontroller & Embeddedsystems, PHI.
7. ArmProcessor Hand book, Dominic Symens

Drives & Actuators

Introduction to Electric motors, Solid state motors devices: SCR, TRIAC, MOSFET, IGBT and their characteristics. Introduction to converters, Inverters, Choppers, cycloconverters

Mechanical characteristics, constant torque and constant HP applications, four quadrantoperation, rating of motors, selection of Drives

Single phase and three phase converters fed drives. DC Brushless (BLDC) conductionmodes(continuous and discontinuous), Operation of drives, Gate drive circuits,performance parameters of converters, Chopper fed drives: Introduction, principle andmodes of operation (four quadrant mode of operation),Types of chopper, closed loopdrives. Self-tuning

Stator & rotor control Drives, V/F control: Principle of operation. VSI &CSI fed drives.Braking methods for induction drives. Rotor resistance control, Slip power recoveryscheme, Comparison of induction motor with servo motor, DC motor to DC Brushless,commutation- physical versus Electronic, Pneumatic/ Hydraulic valves, control elements,Actuator and drive selection Intelligent drive.

Stepper motor- Driver circuit – control algorithm – PID Laws- self tuning strategies

Types of actuators, electromechanical actuators, rotary output actuators, Linear outputactuators, Electro hydraulic actuators, smart actuators, Electro pneumatic actuators,solenoid valves, Features &selection criteria for actuators, spring/Diaphragm actuators,piston actuators.

Types of valves, Ball valve, butterfly valve, digital valves, valves applications,selection criteria for valves, valve sizing

The drive perspective, Hall Resolver, pulse coder

Laboratory Practice
Perform any two practicals from the following list of practicals.
(1) Study of AC and DC drives.
(2) Pneumatic and Hydraulic actuators using trainer kits.

(3) Study of stepper motor drives.
(4) Study of different control valves.

References

1. Sen P.C., Thyristorised D.C. Drives, John Wiley & sons.
2. Murphy J.M.D. & Turnbull F.G., Thyristor control of AC Motors,Pergamon press.
3. B.K.Bose, Power Electronics & A.C. Drives, Prentice Hall Publication.
4. M.Rashid,Power Electronics, Tata Mc GRAW Hill Publications.
5. Dubey G.K., Power semiconductor Drives,Prentice Hall Publication.
6. N.K.De and P.K.Sen, Electric Drives , Prentice Hall Publication.
7. Liptak manual, Process Control