DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY(ISM) DHANABD

SYLLABUS

OF

PhD (MECHANICAL ENGINEERING)

Course work in MACHINE DESIGN

MONSOON SEMESTER

Course No.	**Course Name**	Semester	**L**	**T**	**P**	**CH**
MEC501	Mechanical Vibration	1st	3	0	0	9
MEC502	Numerical Methods	1st	3	0	0	9
MEC503	Finite Element Method	1st	3	0	0	9
MEC591	Research Methodology and Statistics	1st	3	0	0	9
HSI500	Research and Technical Communication	1st	3	0	0	9

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEC 501	Mechanical Vibration	3	0	0	9

Course Objective

- To impart necessary fundamental knowledge to a student so that he can confidently cater to the needs of industry or R & D organizations
- Fourier analysis has been added to understand and address practical problems.

Learning Outcomes

Upon successful completion of this course, students should be able to:

- Understand the concept of vibration
- Apply the concept in solving industrial problems
- Develop software code for a proper mathematical modeling
- Identify a suitable research topic to solve realistic industrial problem

Module	Topics to be Covered	Lecture Hours	Learning Outcome
1	Free vibration of SDF system with and without damping, concept of phase plane, logarithmic decrement, quality factor.	5	Vibration fundamentals. Learning different fundamental concepts in connection with free vibration.

2	Response of single degree of freedom system to periodic and non-periodic excitation, rotating unbalance, whirling of rotating shafts	6	Forced vibration concepts of Single DOF system. Different ways of forcing and its response.
3	Vibration isolation, support motion, absorption and isolation, Measuring instruments.	6	Ways to mitigate vibration problem
4	Transient analysis and impulse response, arbitrary excitation, Laplace Transform formulation, response spectrum.	4	Learning response to various excitation and mathematical models to solve the same.
5	Multi degree of freedom system, normal mode vibration, co-ordinate coupling, modal analysis, orthogonal properties, modal matrix, Lagrange's equation.	6	Fundamental concepts of Multi Degree of Freedom problems and modal analysis.
6	Multi degree of freedom system – exact analysis and numerical methods, classical methods like Rayleigh, Dunkerley, Rayleigh-Ritz, Holzer etc.	5	Analysis of Multi degree of freedom system and learning various numerical techniques.
7	Vibration in continuous system like sting, shaft, bar, beam and membrane. Fourier analysis of signals, Presentation of the results of frequency analysis.	7	Vibration analysis of various continuous systems and Fourier analysis.

Text Book:

1. Theory of vibrations with applications – W. T. Thomson, M.D. Dahleh, C Padmanabhan, Pearson, 5th Edition. (2008)

Other References:

1. Vibration: Fundamentals and practices ,Clarence W.de Silva; CRC press,2nd Ed.2006.
2. Vibration and noise for engineers – K. Pujara; Dhanpat Rai and Co,2013.
3. Vibrations, Waves and Acoustics – D Chattopadhyay and P C Rakshit; Books and Allied(P) Ltd,2019.

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEC502	Numerical Methods	3	0	0	9
Course Objectives						
The objective of the course is to study the numerical solution of linear and non-linear algebraic equations, solution of differentiation, integrations, PDEs and ODEs.						
Learning Outcomes						
Upon successful completion of this course, students will: 1. be able to solve actual problems by using different numerical methods. 2. be able to use FDM for discretization of governing equations to find the temperature distribution in the given geometry. 3. be able to understand the different types of PDEs. 4. be able to use the upwinding for solving the flow problems. 5. be able to write the computer programming based on learning of this course.						

Modules	Topics	Lecture hours	Learning outcomes

1	Introduction to Numerical methods	1	Numerical methods are gradually becoming the substitute of experimental methods
2	Solution of linear algebraic systems: Non-iterative method, Gauss elimination method, LU- factorization method, Matrix inversion method. iterative method, Gauss Seidel iterative method, Jacobi method, ill -conditioning problems, Tridiagonalization, Hoseholder's method, QR-factorization	8	This unit will help students in understanding the numerical solution methodology for linear equations
3	Solution of non-linear algebraic systems: Solution of equations by iterations, Fixed point iterations, Newton's method, Secant method, Bi-section method	5	Understanding the methods for solution of non-linear equations
4	Numerical differentiation: Methods for first order ODEs, Euler method, Runge-Kutta methods, Methods for higher order and systems of ODEs, Euler method, Runge-Kutta methods, Stiff systems	5	This unit will help students in understanding the applications of Euler's Method, R-K2 and higher order R-K 4 methods
5	Numerical integration: Trapezoidal rule, Simpson's 1/3 rule, Simpson's 3/8 rule. Numerical double integration	5	Numerical integrations will be very useful for summation and averaging. Also, students will learn about best technique for integration.
6	Introduction to partial differential equations: 1ST Order PDEs, Mathematical classification second order PDEs, Characteristics	2	Understanding the behavior of PDE equations

7	Finite Difference Methods: Different discretization techniques of PDE equations, Backward, forward and central differencing discretization schemes, Euler's explicit, implicit and semiimplicit methods, Truncation, Discretization, Round off errors. Consistency, stability and convergence. Fourier or von-Neumann stability analysis of Finite difference schemes	8	Understanding different types of errors, consistency, stability and convergence during solving the governing equations
8	Applications to model problems: Parabolic equations, heat equations, Elliptic equations, Laplace and Poisson's equations. Dirichlet problems, ADI method, Neumann and Mixed problems, Hyperbolic equation, wave equation, Upwinding differencing scheme of advection terms	5	Students may use different methods for solving the actual heat/fluid flow and wave equations

Text Books:

1. Introductory Methods of Numerical Analysis: S. S. Sastry, 4th Edition, Prentice Hall of India Pvt Ltd.

References:

2. Numerical Solution of Partial Differential Equations: G. D. Smith, Oxford University Press, 1985.

3. Computational Fluid Mechanics and Heat Transfer: D. A. Anderson, J. C. Tannehill and R. H. Pletcher, Hemisphere Publishing Corporation.

4. Computational Fluid Flow and Heat Transfer: K. Muralidhar and T. R. Sundararajan, Narosa Publishing House.

5. Computational Methods in Engineering: S. P. Venkateshan and P Swaminathan, Ane Books Pvt Ltd.

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEC503	Finite Element Methods	3	0	0	9

Course Objective
• To provide the fundamental concepts of the theory of the finite element method. • To understand the need of numerical method to solving complex problems
Learning Outcomes
Upon successful completion of this course, students will able: • To obtain an understanding of the fundamental theory of the FEA method; • To develop the ability to generate the governing FE equations for systems governed by partial differential equations; • To understand the use of the basic finite elements for structural applications using truss, beam, frame, and plane elements; and • To understand the application and use of the FE method.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction: Fundamental concepts and matrix algebra.	2	Understanding the basic concept of FEM problem and its formulation. Recap of matrix algebra
2	Direct stiffness method: Spring, Truss-coordinate transformation; Shape function in 1D, Governing Differential Equations -strong form and weak form	5	Understand to solve the problem by Direct stiffness method ; And role and significance of shape functions in finite element formulations
3	Approximation Techniques: Potential energy, Rayleigh-Ritz method and Galerkin method. 1D elasticity using the Rayleigh-Ritz Principle	4	Understand to solve the FE problem by different types of Approximate Method
4	Element Properties: Lagrange and Serendipity Elements. Isoparametric Formulation, Stiffness Matrix of Isoparametric Elements. Numerical Integration: 1D & 2D	6	Understand global, local, and natural coordinates. Types and propesries of Element
5	Beam & Frames: Stiffness of Beam Members, Analysis of Continuous Beam, Plane Frame Analysis, Analysis of Grid and Space Frame	7	Understanding the structural element & their FE Formulations
6	2D & 3D element : CST, LST, Rectangular Elements, Axisymmetric Element, 3 D Elements	7	Understanding the 2D and 3D Element & their Isoparametric formulation
7	Plate and shell element: Plane stress & plane strain problems, Introduction to Plate Bending	6	Understanding the thin structural element with

	Problems, FEM of Thin Plate & Thick Plate, Finite Element Analysis of Shell		different Types of Boundary Conditions and Loads
8	FEM programming with MATLAB	2	Understanding how to develop the FEM coding

Text Books:

1. Daryl L. Logan, A first Course of FEM, 5th Edition, Cengage learning

Reference Books:

1. T.R .Chandrupatta and A.D.Belegundu, *Introduction to Finite Element in Engineering*, Pearson Education India; 4 edition (2015)
2. J.N. Reddy, *An Introduction to the Finite Element Method*, Tata McGraw-Hill edition.
3. The finite element method, T. J. R. Hughes, PRENTICE-HALL, INC, Englewood Cliffs, New Jersey.

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEC 591	Research Methodology and Statistics	3	0	0	9
Course Objective						
To illustrate to the students a) the basic concepts of research, b) how a scientific research problem has to be formulated and tackled and c) important statistical tools necessary to analyze the collected data for a meaningful research outcome.						

Learning Outcomes
On successful completion of the course, the students will • Learn various types of research process, methodologies to identify, design and execute a research problem based on scientific and statistical tools; • Learn various types of sample design techniques and its classification, characteristics of a good sample design and how to select a sampling procedure for data collection; • Learn various types of measurement scales, sources of error in measurement and technique of developing measurement tools to evaluate the collected data; • Learn various methods of data collection and the reliability and validity of the collected data; • Learn various ways to prepare and present report for dissemination of research outcome; • Learn various statistical tools necessary for designing a sample, analyzing the data and making scientific conclusion(s) out of the collected data to arrive at a research outcome.

Module	Topics	Lecture Hours	Learning Outcome
1	Research Process, Types of Research, Problem identification and Hypothesis formulation	5	Basic ideas on research processes, Definition of various types of research, Knowledge on what constitute a research and how to identify a research problem,

			Knowledge on the formulation of hypothesis for research
2	Research Design: General Designs of Research, Randomized and Correlated Groups Design.	5	Meaning of research design, Ideas on the need for research design, Knowledge on the features of a good research problem design, Important concepts relating to research design, Ideas on different research design methodologies, Ideas on the basic principles of experimental designs
3	Sampling Design, Measurement and Scaling, Methods of Data Collection, Reliability and Validity	5	Ideas on the Implications of a Sample Design and its classification, Knowledge on the criteria of selecting a sampling procedure and characteristics of a good sample design, Ideas on measurement scales and sources of error in measurement, Knowledge on technique of developing measurement tools, Ideas on the meaning of scaling and important scaling techniques, Ideas on the methods of data collection and the reliability and validity of the collected data.

4	Data Presentation and Report Preparation, Introduction to Qualitative and Quantitative Research Methods.	3	Ideas on Data presentation and report preparation techniques, Sensitizing the students on the very important issues of plagiarism, Preliminary ideas on the qualitative and quantitative research methodologies and their mutual difference.
5	Frequency Distribution, Presentation of Data, Measures of Central Tendency, Measures of Dispersion, Skewness	3	Ideas and knowledge on frequency distribution, cumulative frequency distribution, constructing histograms, Knowledge on the measures of central tendency (Mean, Median and Mode), Various measures of dispersion of the data.
6	Probability Distributions, Discrete and continuous random variable, Binomial, Poisson, Normal and Standard Normal distributions.	6	Learn about Experiment, Outcomes, and Sample Space, Calculation of Probability, Ideas on Marginal and Conditional Probabilities, Learn about Mutually Exclusive, Independent and Complementary Events, Learn about Bay's Theorem, Learn about discrete and continuous random variables and how to calculate their mean and standard deviation, Learn about

			Binomial, Poisson, Normal and Standard Normal distributions.
7	Sampling and Estimation, Sampling Distribution, Estimation of the mean and proportion, Hypothesis tests about the mean and proportion of a population, t-test and z-test, Estimation and hypothesis testing about two different populations.	6	Learn about sampling and estimation methods, hypothesis testing regarding the properties of the population from the sample statistics (sample mean and variance), Learn about Student's t-distribution and z-distribution and t-test and z-tests, Knowledge on estimation and hypothesis testing about two different populations
8	Hypotheses testing: χ^2- test, Analysis of Variance, Correlation and Regression analysis.	6	Learn about the Chi-Square distribution, Goodness-of-Fit test, Learn about making contingency tables, Learn about testing independence or homogeneity of populations, Learn to infer about the population variance, F-Distribution and one-way ANOVA, Learn about simple linear regression models and analysis.

Textbook:

1. 'Research Methodology - Methods and Techniques' C R Kothari and Gaurav Garg New Age International (P) Limited Publishers 4rth Edition, 2019 New Delhi

2. ‘Applied Statistics and Probability for Engineers’ D C. Montgomery and George C. Runger 6 th Edition, 2016

References:

1. Research Methodology: A Step-by-Step Guide for Beginners, Ranjit Kumar, SAGE Publications Ltd; Fifth edition 2018.

Introductory Statistics, Prem S. Mann, 7th Edition, John Wiley and Sons Inc., 2010, Danvers, MA.

HSI500	Research and Technical Communication	1st	3	0	0	9

Syllabus from HSS Dept

WINTER SEMESTER

Four elective courses from Winter Semester

	PG Level Electives	Semester				
Course No.	**Course Name**		**L**	**T**	**P**	**CH**

MED525	Rotor Dynamics	2nd	3	0	0	9
MED526	Finite Element Method for Dynamics and Stability Analysis	2nd	3	0	0	9
MED527	Design of Tribological Components	2nd	3	0	0	9
MED528	Robotics	2nd	3	0	0	9
MED529	Composite Materials	2nd	3	0	0	9
MED530	Theory of Plates and Shells	2nd	3	0	0	9
MED531	Fracture Mechanics	2nd	3	0	0	9
MED532	Theory of Plasticity	2nd	3	0	0	9
MED533	Acoustics and Noise control	2nd	3	0	0	9
MED534	Automation and control	2nd	3	0	0	9
MED535	Vibration Control	2nd	3	0	0	9
MEO577	Structural dynamics and Aero-elasticity	2nd	3	0	0	9
MEO578	Bond Graphs in Modelling and Simulation	2nd	3	0	0	9

MED573	Advanced Optimization Techniques	4th	3	0	0	9
MED562	Failure Analysis and Repair	2nd	3	0	0	9
MED554	Surface Engineering	2nd	3	0	0	9
MED563	Reliability, Availability and Maintainability Engineering	2nd	3	0	0	9
MED564	Erosion and Corrosion of Machine Components	2nd	3	0	0	9
MED565	Nano Technology in Tribology	2nd	3	0	0	9
MED566	Simulation in Maintenance Engineering and Tribology	2nd	3	0	0	9
MEO 588	Risk Analysis and Safety	2nd	3	0	0	9
MEO 589	Maintenance audit	2nd	3	0	0	9
MEO 582	Flow and transport phenomenon through piping system	4th	3	0	0	9

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED525	Rotor Dynamics	3	0	0	9

Course Objective

- The course aims to equip the students to the methods of modelling and analyzing rotating machines for their dynamic behavior.

Learning Outcomes

After completing the course, students will be able to

- derive the equations of motion of rotors in absolute and rotating coordinate systems
- calculate the critical speeds of rotors,
- balance a rotor,
- explain the gyro effect on critical speed

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction: Rotating machine Components, Aspects of rotating machine behavior, examples of rotating machines: Electrical Machines, Turbo generators, Gas Turbines	2	Understanding the significance of rotor dynamics.

2	Introduction to vibration analysis: Single degree of freedom systems, Multiple degrees of freedom systems, Discrete Fourier transform	2	Writing equations of motion of single and multiple degree of freedom system
3	Free lateral response of simple rotor models: Gyroscopic couples, Rigid rotors on flexible supports, Isotropic flexible supports, Simple model for flexible rotors	6	Students will be able to obtain equations of motion of simple rotors
4	Finite element modeling: Finite element modeling of discrete systems, Axial deflection of bar, Lateral deflection of bar, Elemental equations for bar and torsion element,	3	Students will be able to obtain response of continuous systems using finite element
5	Free lateral response of complex systems: Disk elements, Shaft elements, Bearings and seals, Foundation, Free response of complex systems	6	Students will be able to obtain elemental matrices for different rotor elements
6	Forced lateral response: Rotor models, Critical speeds, Mode shapes associated with critical speeds, Stresses in rotors, Asymmetric rotors and instability	5	Students will be able to calculate the critical speeds and mode shapes of rotors
7	Balancing: balancing rigid rotors at design stage, Field balancing of rigid rotors, Field balancing of flexible rotors	6	Students will be able to do calculations for balancing the rotors
8	Axial and Torsional vibration: Simple system models for axial vibration, Simple system models for torsional vibration, Finite element models	6	Students will be able do the axial and torsional vibration analysis of rotors

9	Condition Monitoring of rotating machines: Different faults in rotors and their signatures, Data acquisition, Basic signal processing	3	Understand the vibration signature of different rotor faults

Textbooks:

1. M. I. Friswell, J. E. T. Penny, S. D. Garvey, A. W. Lee, Dynamics of Rotating Machines, 1st edition, Cambridge University Press.

References:

1. Tiwari R., Rotor Systems: Analysis and Identification, 1st edition, CRC Press, Florida.

2. Rao J.S., Rotor Dynamics, 3rd edition, New Age, New Delhi.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED526	Finite Element Method for Dynamics and Stability Analysis	3	0	0	9

Course Objective
• To learn and apply finite element solutions to structural dynamic problem • To develop the knowledge and skills needed to effectively evaluate finite element analyses for stability analysis.

Learning Outcomes
Upon successful completion of this course, students will able: • To obtain an understanding of the dynamics FE theories. • To develop the dynamics stiffness matrix; • To understand the modal reduction techniques and its use • To understand the Nonlinear Dynamics FE analysis.

Module	Topics	Lecture Hours	Learning Outcome
1	Approximate methods and FEM: Hamilton's principle, Rayleigh's quotient,Rayleigh Ritz method and method of weighted residuals	4	Understand to solve the FE problem by different types of Approximate Method
2	Finite element analysis of dynamics of planar trusses and frames: Analysis of axially vibrating rods and Euler-Bernoulli beams, Assembly of matrices ,FE modelling of planar structures	5	Understanding the basic concept of FEM problem and its formulation
3	Analysis of equations of motion: FRF-s and damping models-, Material damping models. Dynamic stiffness and transfer matrices. Analysis of grids and 3D frames: Twisting of circular bars and rectangular bars. Analysis of grids 3D frames	6	Understanding to develop the dynamics stiffness matrix for different critical structure

4	Time integration of equation of motion: Euler's forward and backward difference methods, Central difference method, Energy conservation. Nonlinear systems.	7	Understanding the time integration techniques for dynamic and nonlinear problem
5	Model reduction and sub-structuring schemes; Analysis of 2 and 3 dimensional continua - Plane stress models, 3d Solid element, Axisymmetric models. Plate bending elements., Plate bending elements	7	Understanding the Modal reduction technique
6	Structural stability analysis - Nonlinear dynamical systems, Energy methods in stability analysis, FEM for stability analysis. Dynamic analysis of stability and analysis of time varying systems, Dynamic analysis of stability and analysis of time varying systems., FE modelling of vehicle structure interactions	6	Understanding the Structural stability analysis & FEM for Structural stability analysis
7	FE model updating	4	Understanding the need of model updating & to create an appropriate practical FEM model

Text:

1. Introduction to finite element vibration analysis, Book by M. Petyt, Cambridge.

Reference

2. Vibration Analysis by Finite Element Method, Jong-Shyong Wu

3. Weaver & Johnston, Structural Dynamics by Finite Elements, Prentice Hall.

4. K J Bathe, Finite Element Procedure, Prentice Hall.

5. Shames & Dym, Energy and FEM in Structural Mechanics, Wiley.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED527	Design of Tribological Components	3	0	0	9

Course Objective
The main objective of this course is to promote a better appreciation of the increasingly important role played by tribology at design stage in engineering. It will help in implementing algorithms developed from the basic principles of tribology to a wide range of practical application.
Learning Outcomes
Upon successful completion of this course, students should be able to: • Implement the concept of tribology at the design stage of a mechanical components such as rolling element bearing, gears, seals, clutches , brakes and belt drive • solve industrial problem related to tribological components • Identify a suitable research topic to solve realistic industrial problem

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction: Tribological consideration in design, Conceptual design, Classification of tribological components, Mechanisms of tribological failures in machines, Zero wear concept, Computational techniques in design	3	Concept of tribology at the design stage
2	Rolling Element Bearings: Selecting bearing types and size, Principles and operating limits, Friction and Elastohydrodynamic Lubrication	9	Ability to Select of rolling element bearing for a particular application
3	Dry and Starved Bearings: Dry and semi lubricated bearings, analysis of partially starved bearings, minimum oil supply and temperature of starved bearings	5	Ability to analyse the bearing under different operating situation
4	Gas Lubricated Bearings: Thrust Bearing, Journal bearings, porous bearing	6	Concept of gas lubricated bearing
5	Seal Fundamentals: Classification of seals, Clearance seals, Visco seals, Radial contact seals, Mechanical face seals	5	Ability to design a seal
6	Tribology of Gears: Spur gears, friction and wear of spur gears, contact stresses, lubrication of spur gears, surface failures	4	ability to design a gear for a particular application
7	Design of Dry Frictional Elements: Dry friction concepts, Brakes and Clutches, Friction belts and Dry rubbing bearing	7	Ability to analyse and design clutches brakes and belt drives

Textbooks

1. M M Khonsari and E R Booser,,Applied Tribology: Bearing Design and Lubrication, John Wiley & Sons, 3rd Ed.2017.
2. H Hirani, Fundamentals of Engineering Tribology with Applications, Cambridge University press, 1st Ed.2016.

References

1. G W Stachowiak and A W Batchelor, Engineering Tribology, Butter Worth & Heinemann Publication, 3rd Ed.2005.
2. Ghosh , Mazumdar, and Sarangi, Theory of Lubrication, Tata McGraw Hill Education, 1st Ed.2013.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED 528	Robotics	3	0	0	9

Course Objective
• To expose the students in both the aspects of analyses and applications of robotics.
Learning Outcomes
Upon successful completion of this course, students will: • have a broad understanding of classification of robots and robotic manipulators used in automation industry. • have an understanding about basics of robot dynamics and control.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction: Robot definition, application, robot anatomy; robot classifications and specifications, serial robots.	3	Understanding robot classifications and general applications
2	Actuators: Pneumatic, hydraulic and electric actuators, Stepper motors, DC and AC motors, Selection of motors, Robot end-effectors	4	Learning the actuator sizing procedure and different types of end-effectors
3	Robot sensors: Contact and non-contact sensors; position, velocity, acceleration and force sensors; Robot vision and their interfaces.	4	This unit provides an overview of robotic sensors, vision and interfaces
4	Transformations: Grubler-Kutzbach Criterion; DOF of a Robot Manipulator; Pose or Configuration; Denavit-Hartenberg (DH) Parameters; Homogeneous transformation.	4	Understanding the analytical procedure involved in motion transformation from fixed base to the end-effector
5	Robot kinematics: forward and inverse kinematics, link velocity and acceleration analysis: Jacobian matrix; Singularity.	4	This unit demonstrates the kinematic analysis of serial chain robots
6	Statics: Link forces and moments; Recursive formulas; force and moment recursion at different joints, Role of Jacobian; Force ellipsoid.	5	Learning the relationships between the joint torques/forces, and the Cartesian moments and forces at the end-effector
7	Dynamics: Inertial properties, Euler-Lagrange formulation, Generalized coordinates; Kinetic and potential energy; Newton-Euler equations; recursive robot dynamics-forward and inverse.	6	Analyzing forces and moments causing the motion of different parts of serial chain robotic manipulator

8	Control: Transfer function and state-space representation of a robotic joint, performance and stability of feedback control, P, PI, PD and PID control, state-feedback control, joint controllers; Non-linear control; stability and force control.	6	Using linear and nonlinear control techniques when a robot moves slowly
9	Applications: Robots in materials handling, machine loading/unloading and programming for case study.	3	Understanding robotic applications and learning code for real-time controlling of simple robots.

Total: 39

Text Books:

1. Introduction to Robotics by S. K. Saha, McGraw Hill,2ndEdition,2014

Reference Books:

2. Introduction to Robotics: Mechanics and Control by John J. Craig,, Prentice Hall

, Robot Modeling and Control by Mark W. Spong Wiley

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED529	Composite Materials	3	0	0	9

Course Objective

- To learn the properties of fiber-reinforced polymer composites
- To learn the mechanical performance of laminated composites, including failure behavior.
- To model, simulate and optimize the performance of composite structures.

Learning Outcomes

Upon successful completion of this course, students will able to:

- Identify, describe and evaluate the properties of fibre reinforcements, polymer matrix materials and commercial composites.
- Develop competency in one or more common composite manufacturing techniques, and be able to select the appropriate technique for manufacture of fibre-reinforced composite products.
- Analyse the elastic properties and simulate the mechanical performance of composite laminates; and understand and predict the failure behaviour of fibre-reinforced composites
- Apply knowledge of composite mechanical performance and manufacturing methods to a composites design project

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction to composites: Brief History, Constituent Materials, Laminate , FRP, micro-mechanics & macro-mechanics, Applications	2	Understand the Composite, its advantage, classification and the terminology used for studying mechanics of composites

2	Fabrication: Liquid resin impregnation routes, Pre-Pregs methods, Consolidation of resin moulding compounds, Injection moulding and hot pressing of thermoplastics. Fabrication of metal matrix composite.	4	Understanding the manufacturing process of composite
3	Micromechanical Analysis: Assumptions, strength-stiffness, Shear , Poisson Ration	6	Develop concepts of volume and weight fraction of fiber and matrix, density and void fraction in composites
4	Elastic Properties of Unidirectional Lamina: , stress – strain relations for general anisotropic, specially orthotropic and transversely isotropic materials, Transformation Matrix	7	Find the engineering constants; Develop stress-strain relationships, elastic moduli, strengths of a unidirectional/bidirectional lamina
5	Analysis of Laminated Composites: Classical Laminate Theory, Displacement Field, Strain Displacements Relations, Constitutive Relations, Classification of Laminates and their properties.	8	Find the elastic stiffnesses of laminate based on the elastic moduli of individual laminas and the stacking sequence
6	Analysis of Laminated Plate & FEM: Classical Plate theory, Bending of composite plate, Shear deformation theories: FSDT, HSDT, Layerwise	6	Ability to analyze problems on bending, buckling, and vibration of laminated plates and beams
7	Hygrothermal Effects of Laminates , Failure Theories and Strength of Unidirectional Lamina Design of Composite structure & Example	6	Develop the relationships of mechanical and hygrothermal loads applied to a laminate to strains and stresses in each lamina

Text:

1. Mechanics of Composite Material & Structures, M Mukhopadhyay, Universities press 2013.

References:

1. An Introduction to Composite Materials, By D. Hull and Clyne, Cambridge University Press 2010
2. Engineering mechanics of composite materials, I. M. Daniel & O. Ishai, 2nd edn., oxford university press, 2006.
3. Principles of composite material mechanics, R. F. Gibson, 2nd edn. CRC Press, 2007.
4. Mechanics of Composite Material, Autar K. Kaw, CRC Press
5. Mechanics of composite materials, Rr. M. Jones, 2nd edn. Taylor & francis, 1999.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED530	Theory of Plates and Shells	3	0	0	9

Course Objective
• To study the behaviour of the plates and shells with different geometry under various types of loads. • To understand theory and design of plate and thin shell structures of different geometries.

• To understand the basic governing differential equations involved for analysing the plate and shell structure. • To understand the solution techniques for bending of the plate and shells under various types of loading.
Learning Outcomes
Upon successful completion of this course, students will: • have a broad understanding formulation of engineering structure under loading. • have an understanding about different boundary conditions and there uses for the solution of the problem . • be able to solve inversely the bending problem of plate and shell.

Module	Topics	Lecture Hours	Learning outcomes
1	Introduction to elasticity (pre-requisite of this course).	4	Understanding the basic concept of classical elasticity theory
2	Introduction to Plates: Classification of Plates, Basic Theory of Plate Bending, Governing Equations of Plates, Boundary Conditions on different Edges, Governing Equations for Deflection of Plate	9	Understand the basic theory, governing equations and design of plate structures.

3	Rectangular plates: Navier's Solution for Simply Supported Rectangular Plates, Levy's Solution for Rectangular Plates, Method of Superposition.	9	Student will learn the solution technique for the bending of a rectangular plate with different boundary conditions.
4	Circular Plates: Basic Relation in Polar Coordinates, Symmetrical Bending of Uniformly Loaded Circular Plates, Symmetrical Bending under point loading, Annular plates.	8	Student will learn the bending relationship of a circular plates under various loading condition.
5	Shells structure: Introduction, Parametric representation of a surface, Governing Equations of Shells, Boundary Conditions, Governing Equations for bending of shells, Analysis of Shells	9	Understand the basic theory and design of shell structures of different geometries.

Text Books:

1. C. Ugural, *Stresses in Plates and Shells*, 2nd ed., McGraw-Hill, 1999

Reference Books:

4. S. P. Timoshenko and S. Woinowsky-Krieger, *Theory of Plates and Shells*, McGraw Hill Pub

5. Analysis of plates by T.K.Varadan and K.Bhaskar , Narosa Publishing House, 1999

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED531	Fracture Mechanics	3	0	0	9

Course Objective
• To make the students conversant with the fundamentals of crack propagation in materials and structures. • This includes development of the strain energy release rate (GIC) and the critical stress intensity factor (KIC). • Emphasis will be placed on developing the correlation between microstructure control and the resistance to crack propagation which this variable produces
Learning Outcomes
Upon successful completion of this course, students will: • have a broad understanding on the fracture behavior of materials. • have an understanding about different types of the fracture and the their post effect on the material behavior • be able to solve the fracture mechanics problem.

Module	Topics	Lecture Hours	Learning outcomes

1	Overview of Engineering Fracture Mechanics: Types of fracture, Microstructural description of fracture, Mechanisms of Fracture, Review of Theory of Elasticity, Stress concentration factor.	4	Understanding the basic concept of material behaviour and their mechanics
2	Tensor and Index Notation: Einstein summation convention, Free indices, Kronecker delta, Permutation symbol, Tensors of various ranks, Partial derivatives, Governing Eqs in index notation	8	Understand the basic mathematical preliminary required to deal for the analysis of fracture mechanics problem
3	Linear Elastic Fracture Mechanics (LEFM): Asymptotic field, Airy stress function, Stress intensity factors (SIF), K_{I}, K_{II}, K_{III}, Determination of SIF, Fracture toughness, Irwin's criterion, K-dominance, Small scale yielding, Fracture testing, Structure design by LEFM.	8	Student will learn the concept of linear fracture mechanics and related theories
4	Energy Approach: Energy release rate G, Griffith criterion, Relationship between G and K, J-integral	8	Student will learn the energy concept in fracture mechanics
5	Nonlinear Fracture Mechanics: HRR-singularity field, J-dominance, Small scale yielding, Large scale yielding, Crack initiation and growth.	7	Understand the nonlinear fracture mechanics problem

6	Fracture Resistance of Materials: Fracture criteria, effect of alloying and second phase particles, effect of processing and anisotropy, effect of temperature, closure.	4	Student will get idea of the effect of inclusion of foreign particles and processing anisotropy on the fracture behavior

Text Book:

1. D. Broek: Elementary Engineering Fracture Mechanics, Springer; 4th edition (1982)

Reference Book:

1. Prashant Kumar: Elements of Fracture Mechanics, McGraw-Hill (2009), ISBN: 9780070656963
2. T. L. Anderson: Fracture Mechanics: Fundamentals and Applications,CRC Press,2 edition (1994), ISBN-10: 0849342600
3. Richard W. Hertzberg: Deformation and Fracture Mechanics of Engineering Materials, Wiley (1995),ISBN-10: 0471012149

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED532	Theory of Plasticity	3	0	0	9

Course Objective
• To study the elastic plastic behavior of the engineering materials under various types of loads. • To understand theory and design of material flow.

• To understand the basic governing equations involved for analysing flow behaviour of the materials. • To understands the role of yield criteria in determining the elastic limit under multiaxial stress and the various theories involved.
Learning Outcomes
Upon successful completion of this course, students will: • have a broad understanding on the mechanism of plastic deformation from fundamentals of material science. • have an understanding about plasticity theory and there uses for the solution of the problem . • be able to solve the problem of generic engineering components under plastic deformation.

Module	Topics	Lecture Hours	Learning outcomes
1	Mathematical preliminaries and Introduction to elasticity (pre-requisite of this course).	4	Understanding the Cartesian tensor algebra and the basic concept of classical elasticity theory
2	Introduction to plasticity theory:	9	Understanding the basic materials behaviour beyond elastic limit, governing equations and flow behaviour.

	Stress and strain; constitutive responses; physics of plasticity; application of plasticity theory for different materials;		
3	Formulation of rate-independent plasticity; maximum dissipation postulate; yield criteria; Flow rules and hardening rules.	9	Student will learn the mathematical description of the non-linear behavior of solid materials.
4	Uniqueness theorems; extremum principles in plasticity; limit analysis; shakedown theorems. plane problems in plasticity; slip line theory and its applications; plastic stability;	8	Student will learn various plasticity theorem and their limitation to estimate deformations and collapsed loads in engineering applications.
5	Plastic buckling; global and local criteria of plastic stability; strain localization and shear bands	9	Basic understanding on the application of plasticity theory such as buckling and bending of beams.

Text Books:

2. Plasticty Theory, J. Lubliner, 2nd ed., McGraw-Hill, 1999

Reference Books:

3. Fundamentals of the theory of plasticity, L. M. Kachanov
4. Nonlinear Solid Mechanics, D. Bigoni
5. Plasticity: Fundamentals and applications, P. M. Dixit and U. S. Dixit

6. Theory of Plasticity, J. Chakrabarty

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED 533	Acoustics and Noise control	3	0	0	9

Course Objective
• Noise and Harshness has become a major issue in today's society, which calls for a quitter technology. • This course will be extremely useful for engineers and researchers to design quitter machines or machine components.

Learning Outcomes
Upon successful completion of this course, students should be able to: • Understand the concept of technical acoustics • Apply the concept in solving industrial problems • Develop software code for a proper mathematical modeling • Identify a suitable research topic to solve realistic industrial problem

Unit No.	Topics	Lecture Hours	Learning Outcome
1	Fundamentals of vibration, Sound and vibration, Acoustics and engineers, basics of acoustics, dB levels, Concept of acoustic impedance etc.	5	Brush up of Vibration fundamentals. Introducing acoustics to aspiring engineers.
2	Type of waves, Characteristic of waves, Mathematical models of sound waves, 3D Wave equation,	6	Acoustic wave phenomena and developing various mathematical models.
3	Acoustics of cavity, Helmholtz resonator, noise control techniques, Noise Control Application, Acoustics of Mufflers etc.	8	Different types of noise control techniques and devices.
4	Experimental Techniques, Source Modeling, Acoustic Structure Interaction, Sound Radiation from Vibrating Infinite Plate.	8	Learning how sound interact with different structures and quantifying sound radiation from the structure.
5	Types of Microphones and specifications, Octave bands.	2	Introducing sensors to pickup acoustic signals and their analysis.
6	Wavenumber space, K-Space Diagram, Concept of Angular Spectrum, Green's function, Rayleigh Integral, Velocity and far field pressure calculations, Directivity and Sound power calculation.	10	Learning various mathematical techniques to predict sound power level at a distance from the source.

Text Book

1. M. L. Munjal. Noise and Vibration Control, World Scientific Press: Singapore (2014).

2. Lawrence E. Kinsler, Austin R. Frey, Alan B. Coppens and James V. Sanders . Fundamentals of Acoustics, Wiley: New York (1999).

Other References

1. Uno Ingard. Notes on Acoustics, Firewal Media: Delhi (2010).
2. E. G. Williams. Fourier Acoustics: Sound Radiation and Near Field Acoustic Holography, Academic Press: New York (1999).
3. Acoustics of Ducts and Mufflers, 2nd Edition,M. L. Munjal, John Wiley and Sons, ISBN: 978-1-118-44312-5.(2014)

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED 534	Automation and control	3	0	0	9

Course Objective
• The course is intended to provide knowledge of any industrial operations involving control of position, velocity, temperature, pressure etc. • It is desirable that most engineers and scientists are familiar with theory and practice of automatic control.

Learning Outcomes			
Upon successful completion of this course, students will: • have a broad understanding of open-loop and closed-loop control system used in practice. • be able to compare the performance of different control systems by using both the time response and the frequency response method.			
Unit No.	Topics	Lecture Hours	Learning Outcome
1	Introduction: Review of Laplace Transform, Close-loop control versus open-loop control, Linear Time Invariant (LTI) systems.	3	Understanding basics of close-loop and open-loop control systems
2	Representation of physical system: Transfer function and impulse response function, modelling in state space, transformation of mathematical models with MATLAB, signal flow graphs, linearization of nonlinear mathematical models	5	To enable students to model dynamic systems and analyze dynamic characteristics
3	Mathematical modeling of control systems: Mechanical, Electrical and Electronic systems, liquid-level systems, pneumatic and hydraulic systems.	5	The students will be introduced the concepts of resistance and capacitance to describe the dynamics of control systems
4	Time response analysis: Transient and Steady-State Response Analyses, 1st order, 2nd order and higher-order systems, Routh's Stability Criterion, Effects of Integral and Derivative Control Actions on System Performance, Steady-State Errors in Unity-Feedback Control Systems,	5	Understanding the basis for performance analysis of control systems by specifying test input signals

5	Control Systems Analysis and Design by the Root-Locus Method: Plotting Root Loci with MATLAB, Root-Locus Plots of Positive Feedback Systems, Lag, Lead and Lag–Lead Compensation	6	Understanding the movement of the closed-loop poles in the s-plane and modification of the dynamics to satisfy the given specifications
6	Frequency-Response Method: Bode Diagrams, Polar Plots, Log-Magnitude-versus-Phase Plots, Nyquist Stability Criterion	7	The students will be able to use the data obtained from measurements on the physical system for control without deriving its mathematical model.
7	PID Controllers: Ziegler–Nichols Rules for Tuning PID Controllers, Design of PID Controllers with Frequency-Response Approach	4	The students will learn different procedures for tuning gain values of PID controllers used in practice
8	Case study by using MATLAB	4	Application of basic control theory in realistic problems and analyses

Total 39

Text book

1. Modern Control Engineering by K.Ogata, 5th edition, Prentice Hall, 2010.

Reference books:

1. Automatic Control Engineering by F.H.Raven, 5th ed., McGraw Hill International, 1994.
2. Digital Control Systems by B.C.Kuo, Prentice Hall.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED535	Vibration Control	3	0	0	9

Course Objective
• To develop the bridge between the structural dynamics and control communities • To providing an overview of the potential of smart materials for sensing & actuating purpose in active vibration control. • To understand the passive damping techniques.
Learning Outcomes
Upon successful completion of this course, students will: • Understand the smart material, actuator sensor • Understand the design consideration to suppress the vibration • Understand the active control of space vehicle, satellite submarine etc

Unit No.	Topics	Lecture Hours	Learning Outcome
1	Review of Basics of Mechanical Vibrations. Basics of Vibrations for Simple Mechanical Systems, Introduction to Damping in Free and Force	6	Understand the basics of Vibration and its types

	Vibrations, Free and Forced Vibrations of Two Degree of Systems, Multi Degree of Freedom Systems		
2	Basics of Vibrations Control: Reduction at source , Feedback Control System, Shunt Damping	6	Understand the preliminary Vibration control strategies.
3	Vibration Isolation, Vibration Generation Mechanism,: Source Classification, Self Excitation Vibration, Flow Induction Vibration, Damping: Models and Measures	6	Understanding the source of vibrations and Isolation of the source & use of damper
4	Design Considerations in Material Selection: Design Sensitivity ,Design Specification, Design for Enhanced Material Damping	6	Understanding the design consideration to suppress the vibration
5	Principles of Passive Vibration Control: Basics of Passive Vibration Control. Design of Absorber, Shock Absorber, Isolators with Stiffness and Damping	5	Understanding the passive vibration control strategy
6	Principles of Active Vibration Control: Basics of Active Vibration Control, Piezoelectric Material , Piezoelectric Accelerometers	5	Understanding the Use active material, actuator and sensor for vibration control
7	Electro-rheological (ER) Fluids , Magneto-rheological (MR) Fluids, Magneto and Electrostrictive Materials, Shape Memory Alloy	5	Understanding the advanced active control units and materials

Text:

1. Principles of Vibration Control by A.K. Mallik, East-West Press

Reference:

1. Vibration Control of Active Structures - An Introduction by André Preumont, springer

2. Passive and Active Structural Vibration Control in Civil Engineering, edited by T.T. Soong, M.C. Costantinou, Springer

3. Mechanical Vibrations: Active and Passive Control by Tomasz Krysinski and François Malburet

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	MEO577	Structural Dynamics and Aeroelasticity	3	0	0	9

Course Objective
• To learn the concept of modal analysis, various methods of structural dynamics analysis of simple beam structures and simplified analysis of such aeroelastic phenomena as divergence, control-surface reversal, and flutter. • To learn the importance of incorporating aeroelastic phenomena in aircraft design and some elementary methods for doing so.
Learning Outcomes
Upon successful completion of this course, students will be: • Familiar with modal representation and to be able to solve elementary structural dynamics problems for beams; • Able to formulate and solve static aeroelasticity problems such as typical section and wing divergence problems;

- Able to use simplified unsteady aerodynamic theories to formulate and solve typical section flutter problems with one and two degrees of freedom
- Developed a qualitative understanding of the role of aeroelastic phenomena, such as divergence, control-surface reversal, and flutter, in aircraft design and performance.

Unit No.	Topics	Lecture Hours	Learning Outcome
1	Introduction : Structural Dynamics, Uniform Beam Bending , Beam Torsion	7	Understanding the modal representation and solve elementary structural dynamics problems for beams
2	Torsional divergence and static airload distributions, Complete vehicle equilibrium and sweep effects, Control effectiveness and reversal of complete vehicle	8	Understanding the formulation and solution of static aeroelasticity problems
3	Lifting surface flutter, flutter analysis using modal representation, the p, k and p-k methods of solutions, effects of Mach number, altitude and mass ratio	9	Understanding the simplification of unsteady aerodynamic theories to formulate and solve typical section flutter problems
4	panel flutter, linear theory for flat panels and design considerations	7	Understanding the supersonic flutter theories
5	Assumed mode solutions for flat and cylindrical panels, Non-linear theory for flat panels and development of fatigue criteria.	8	Understanding the supersonic flutter theories

Text:

1. D.H. Hodges and G.A. Pierce, "Introduction to Structural Dynamics and Aeroelasticity" Cambridge Aerospace Series, 2012.

Reference:

1. E.H. Dowell et.al., "A Modern Course in Aero elasticity", Sijthoff & Noordhoff, 1980..
2. R.L. Bisplinghoff and H. Ashley, "Principles of Aeroelasticity", Dover, 1962.
3. Y.C. Fung, "An Introduction to the Theory of Aeroelasticity", John Wiley & sons, 1955.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	MEO578	Bond Graphs in Modelling and Simulation	3	0	0	9

Course Objective
• The requirements of a unified approach to modelling, simulation and synthesis of physical system is quite prominent among industries and R&D sectors, in particular. • This course will impart a lesson to create a unified and mathematical model, which may be subjected to predictive or deductive processes
Learning Outcomes
Upon successful completion of this course, students will: • Get a lesson on how to make mathematical models of different physical systems using bond graph approach • Understand a systematic procedure for systems’ equations generation through the direct exploitation of cause and effect relationship.

- Learn to bring out the power of bond graph modelling in developing control strategies from physical paradigms.

Unit No.	Topics	Lecture Hours	Learning Outcome
1	Elements of analytical mechanics: An invariant nature of power exchange, power variables, reference power directions, bond graphic elements and physical system coordinates.	2	Understanding the basic bond graphic elements and their correlations with the analytical mechanics.
2	The notion of causality: Information exchange and its laws, causality of active and passive elements, junction elements, two-port elements, differential causality, algorithm for assigning causality, causal loop.	3	This unit discusses the notion of causation to incorporate all aspects such as interaction with exterior, storage and constraints of a general system.
3	Creation of system equations: Selection of system states, deriving equations of motion of mechanical and electrical system through bond graph model, systems with differential causality, activated bonds, system equations of motion with field elements, algebraic loops.	3	Student will learn the method of generation of system equations from an augmented bond graph using a step by step procedure.
4	Bond graph modelling methods: Method of flow and effort map, method of gradual uncover, point potential method, gyrator and transformer equivalents.	3	Students will be accustomed with different styles of mapping used in modelling.
5	Modeling in noninertial coordinates: Dynamics of rigid bodies, principle of material objectivity, generalized momenta, compliant fields	4	This unit demonstrates the art of modelling of complex systems having nonlinearity in dynamics
6	Structural members: Euler-Bernoulli beam model, Raleigh beam model, beam-column, consistent inertia field, transverse vibration of uniform beam under transverse loads and moments	4	This unit discusses modeling of beams through various levels of refinements followed by modal bond graph or finite mode analysis.

7	Modelling of multibody systems: Slider-crank and four bar mechanism, mechanical handling systems, modelling of robot, determination of transfer moduli for 5 DOF robot.	3	This unit deals with bond graph modeling of mechanisms, simple load hoisting systems and robotic manipulators.
8	Modelling of power hydraulic systems: Power variables for hydraulic circuits, hydraulic compliances, viscous resistance, hydraulic gyrator and transformer, bond graph model of a hydraulic servomotor.	7	Students will be able to understand the concepts relevant to system dynamics of hydraulic circuits
9	Application of bond graphs to control systems: Signal flow graph from bond graph, position control of a mass on a spring-damper combination, PID control, velocity control of moving cars connected by a spring	3	The students will learn to formulate transfer functions for linear time invariant systems from their bond graph models via signal flow graphs and once transfer functions are obtained, further analysis may be routinely carried on by the techniques well developed in classical control theory of these systems.
10	Introduction to software SYMBOLS-6.0 modelling and simulation practice of some real-life problems.	7	Students will learn handling a new software for simulation of system dynamics

Text Books:

1. Bond Graph in Modeling, Simulation and Fault Identification, by Mukherjee, A., Karmakar, R. and Samantaray, A.K., 2006, I. K. International: New Delhi, India, ISBN 81-88237-96-5.

Reference Books:

1. System dynamics: A unified approach, by Karnopp, D.C., Margolis, D.C. and Rosenberg, R., 1990, John Wiley, New York.

2. Bond graphs - A methodology for modelling multidisciplinary dynamic systems, Borutzky W., 2004, SCS Publishing House, Erlangen, San Diego.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	MED573	Advanced Optimization Techniques	3	0	0	9

Course Objective
- To understand theory of different optimization methods to solve various types of engineering problems.   - To understand physical engineering problem and to construct mathematical formulation towards solving it by selecting proper optimization techniques.   - To understand both computer programming and heuristic approaches to solve optimization problems.
Learning Outcomes
Upon successful completion of this course, students will: - have a broad understanding formulation of engineering optimization problem.   - have an understanding about single and multivariable engineering problems.   - be able to write MATLAB code for single and multivariable engineering problems.   - be able to understand and write MATLAB code for Nontraditional optimization technique like GA to solve different engineering problems.

Unit No.	Topics	Lecture Hours	Learning Outcome
1	Basic Concepts: optimization problem formulation.	4	Understanding the types and basic concept of engineering optimization problem formulation.
2	Single variable optimization algorithms: Exhaustive search method, bounding phase method, Interval halving method, golden search method, Newton Rapshon method, bisection method, secant	9	This unit discuss about different types of classical single variable optimization algorithms. Student will learn to write MATLAB code for these algorithms also.

	method. Computer programming to solve the single variable problem		
3	Multivariable optimization algorithms: Unidirectional search, direct search methods, simplex search and gradient based methods. Computer programming to solve Multivariable optimization algorithm	9	This unit discuss about different types of classical multivariable unconstrained optimization algorithms. Student will learn to write MATLAB code for these algorithms also.
4	Constrained optimization algorithms: Linear programming, nonlinear programming penalty function method, method of multipliers, sensitivity analysis, direct search for constrained minimization. Related computer Programming.	8	Student will learn constrained optimization algorithms and their computer programming.
5	Nontraditional optimization: Introduction to Genetic algorithm: Binary coded GA, Limitation – advantage & disadvantage Real coded GA, Micro GA, Scheduling of GA, computer programming, other evolutionary algorithms.	9	This unit demonstrates basics of Nontraditional optimization techniques. Use of Nontraditional optimization like GA to solve different engineering problem, especially mechanical engineering problems.

Text Books:

1. Deb, K. Optimization for engineering design: algorithms and examples. Prentice Hall of India, New Delhi. 2nd Edition 2012

Reference Books:

6. Rao, S.S. Engineering Optimization: Theory and Practice. Wiley. 3rd Edition, 2014
7. Ravindran, A., Ragsdell, K. M., Reklaitis, G. V. Engineering Optimization: Methods and Applications, Willey, 2nd Edition, 2013
8. Rardin, Ronald L. Optimization in operations research. Prentice Hall.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED554	Surface Engineering	3	0	0	9

Course Objective
To have systematic and comprehensive understanding on various aspects related with surface engineering of metallic components.
Learning Outcomes
Upon successful completion of this course, students will able to: • Identify and design the suitable surface modification methods for different applications • Characterise the metallurgical, mechanical and tribological properties of engineered surfaces.

Module	Topics	Lecture Hours	Learning Outcome
1	Fundamentals of surface engineering: definition, scope, classification, and general principles, surface dependent properties and failures, Surface and surface energy: Structure and types of interfaces.	4	Understanding of surface properties and their influences on the performance of a component.
2	Conventional surface engineering practice: Surface engineering by material removal: like etching, grinding, polishing, etc. Surface engineering by material addition: like hot dipping, Electro-plating, carburizing, Cyaniding, etc.	6	Understanding on the fundamental of basic surface modification techniques.
3	Surface engineering by energy beams: Laser assisted microstructural modification like surface melting, hardening, shocking etc., Laser assisted compositional modification like surface alloying, surface cladding, composite surfacing etc. Surface engineering by spray techniques like Flame spray, cold spray etc.,	12	Understanding of thick layer coating technology and their applications.

4	Ion beam assisted microstructure and compositional modification, Sputter deposition of thin films & coatings, PVD coating processes, Chemical vapour deposition and PECVD.	10	Understanding of thin layer coating technology and their applications.
5	Characterization of coatings and surfaces: Measurement of coatings thickness, porosity & adhesion of surface coatings, Measurement of residual stress & stability, Surface microscopy, topography and Spectroscopic analysis of modified surfaces.	7	Understanding about methods of characterization needed for evaluating the metallurgical, mechanical and tribological properties of engineered surfaces.

Text books:

1. Introduction to Surface Engineering by P. A. Dearnley, Cambridge University Press, 2017
2. Laser surface modification of alloys for corrosion and wear resistance by Chi Tat Kwok, Woodhead Publishing Limited, 2012

Reference books:

1. Surface Engineering for Corrosion and Wear Resistance by J.R. Davis, ASM international , 2001
2. ASM Hand book – Surface Engineering, ASM International, vol. 5, 9th edition, 1994

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED 562	**Failure Analysis and Repair**	3	0	0	9

Course Objective
The objective of the course is to equip students with various techniques of failure analysis in order to solve real life problems related to the failures and associated repair and maintenance of equipment/components.
Learning Outcomes
Upon successful completion of this course, students will: • Be able to understand failure of components. • Be able to modes and causes of failures. • Be able to learn failures due to residual stresses, temperature and cracks. • Be able to learn types of analyses of failures and remedies as well as remedies. • Be able to solve problems related to repair components and machines in the industries by use of repair software

Module	Topics	Lecture Hours	Learning Outcome

1	Introduction, Need for failure analysis, Classification of failures, Fundamental causes of failures, Ishikawa Diagram, Influence of types of loading (e.g. static, fatigue, shock, etc.) on nature of failures, Role of stress; Process and fabrication defects.	4	This unit will help learn basics of failures of components/machines.
2	Effect of residual stresses induced during fabrication processes, Influence of temperature and environment on failure, Crack and subsurface crack like defects and their significance in failure.	3	This unit will help students in gaining knowledge about failure due to stresses, temperature and cracks.
3	Micro mechanisms of failures; Ductile and brittle fracture, Fracture initiation and propagation, Fatigue failures, Wear related failures, High temperature failures, Low temperature failures, etc., Studies and analysis of failed surfaces	8	Understanding of various mechanisms and types of failures.
4	Identification of failures, Techniques of failure analysis, Risk analysis and Risk Matrix; RCM concept; FTA and ETA technique; FMECA, PHA and HAZOP analysis; Fracture mechanics, Prediction of failures, Residual life assessment and life extension	9	This unit will help students in learning about types of analysis of failures.
5	Typical case studies in failure analysis, Logical fault finding and its application, Inspection and safety measures, Repair techniques and economic considerations	9	This unit will help in learning case studies of failure and associated safety measures as well as repair.
6	Failure analysis for design improvement and proactive maintenance, Design for reparability, Case Studies. ALD Reliability /Thermo-Calc Software	6	This unit will help students to learn about design improvement in the machine to prevent failure and learn about associated software for repair.

Textbooks

Failure Analysis : Fundamentals and Applications in Mechanical Components
Otegui Jose Luis 2014 Springer International Publishing AG

Reference Book

1. Practical Engineering Failure Analysis
   Hani M. Tawancy, Anwar Ul-Hamid, Nureddin M. Abbas
   Series: Mechanical Engineering 1st Ed. 2004 CRC Press
2. ALD Reliability /Thermo-Calc-Software.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED 563	**Reliability, Availability and Maintainability Engineering**	3	0	0	9

Course Objective

The objective of the course is to study the basic theory of reliability, maintainability and availability, various static and dynamic model probability models for predicting the particular natural failures in machines. To equip students with various reliability techniques in order to solve real life industrial problems and the applications of the latest Reliasoft Weibull + Software

Learning Outcomes

Upon successful completion of this course, students will:

- Be able to familiar with reliability methods and their applications.
- Be able to use the specific reliability models for probability analysis of events and failures.
- Be able to understand the applications and importance of the reliability models in industries.
- Be able to use Markov and Weibull reliability models and their applications

Module	Topics	Lecture Hours	Learning Outcome
1	Fundamentals of reliability and availability and maintainability(RAM), System concepts in RAM Engineering	5	This will familiarise with reliability analysis its importance in industries.
2	Failure distributions, Statistical analysis of failure data, Weibull analysis, Monte Carlo simulation	10	This unit will help students in understanding the various basic reliability models such static and dynamic and their application .
3	System reliability assessment, Point, mission and steady state availability, Availability assessment	5	This will help the students to understand the systems reliability when its components are arranged in series, parallel, redundant etc.
4	Reliability of repairable and non-repairable systems	4	This unit will help students to understand the methods of assessment of reliability of repairable and non-repairable systems.

5	Maintainability assessment. Design for reliability and maintainability	5	This chapters will familiarise students with reliability assessment of machines, how to ensure its maintenance under various constraints such as availability of spares, shutdown, financial resources.
6	Practical applications of RAM Engineering to systems, products and processes. Reliasoft Weibull ++ Software	10	This chapter will help the students to understand the in-depth probability of failures and reliability of the system of software by use of software.

Textbooks

1. An Introduction to Reliability and Maintainability Engineering Charles Ebeling 12 edition 2017 McGraw Hill Education
2. Jardine, A.K.S. and Tsang, A.H.C. (2013). Maintenance, Replacement, and Reliability: Theory and Applications. CRC Press, Taylor & Francis Group LLC.
3. Software Recommended for Reliability Analysis and Modelling: Reliasoft Corporation (2003). Reliasoft Weibull++ Software

References:

1. Blischke, W.R. and Murthy, D.N.P. (2003). Case Studies in Reliability and Maintenance, John Wiley & Sons.
2. Barlow, R.E. and Proschan, F. (1965). Mathematical Theory of Reliability. John Wiley, New York.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED 564	Erosion and Corrosion of Machine Components	3	0	0	9

Course Objective

- To understand theory of wear and friction.
- To study erosion and corrosion principles in machine components
- To understand reason behind real life industrial problem
- To develop research ideas to improve and design different machine components involve in power sector

Learning Outcomes

Upon successful completion of this course, students will:

- have a broad understanding about origin of friction and mechanism behind wear.

- have an understanding about different materials, their anti-erosion and corrosion properties and their application in real life problem.
- be able to write MATLAB code and use soft techniques to solve different problems.
- be able to understand reason behind erosion and corrosion related real life industrial problems and their remedy

Module	Topics	Lecture Hours	Learning Outcome
1	Basic Concepts: fundamentals of tribology, Importance of erosion and corrosion control in industrial practices.	2	Understanding the definition and history of tribology and their industrial significance are described.
2	Fundamentals of friction and wear theory: Solid–Solid Contact, Liquid-Mediated Contact, Friction of Materials, Types of Wear Mechanism, Types of Particles Present in Wear Debris, Wear of Materials. Solution of friction and wear problems and statistical estimation of surface properties using soft techniques.	5	Understanding the origins of the frictional force, and try the magnitude of the frictional interactions between metals, polymers, ceramics and other materials. To understand progressive loss of material, due to the relative motion between the surface and contacting material or substance
3	Fundamentals of abrasive Erosion Theory: Mechanism of abrasive effect produced by particles, abrasive erosion of machine components. Calculation of abrasion, analysis.	8	Understanding the hydraulic abrasion of the flow-passage components of hydraulic machines like hydro-turbines, pumps etc.
4	Erosion-resistant materials: selection of erosion-resistant materials, surface treatment against erosion damage. Organic Polymer Linings, Ceramics, Metal Protective Coating, Non-Metallic Protection Coating	8	Understanding different mechanism of erosion resistant materials and \their applications
5	Thermodynamics of corrosion. Fundamentals and application of corrosion theories, interaction of corrosion with erosion. Corrosion Control- Design improvement.	7	To estimate the temperature rise at a sliding contact that results from frictional energy dissipation.
6	Erosion and corrosion on machine components. Analysis and Numerical Simulation of Liquid-Solid Two-Phase through Hydraulic Machinery. Case studies on modelling of a machine component for studying erosion using ANSYS	9	To understand how to solve real life industrial problem related to erosion and corrosion.

Text Books:

1. Introduction to Tribology, second edition, Bharat Bhushan, Wiley

Reference Books:

1. Abrasive Erosion and Corrosion of Hydraulic Machinery, C. G. Duan, Y. Y. Karelin, Imperial College Press, 2002.
2. Guide to Wear Problems and Testing for Industry, M J Neale and M Gee, William Andrew Inc. Pub., 2001
3. Hydraulic machines guide for dealing with abrasive erosion in water. IEC 62364 Ed. 1.0, 2009.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED565	**Nano Technology in Tribology**	3	0	0	9

To understand, characterize and modify surfaces for scientific and technological applications and the effect of nanotechnology on surface topology at the Nano scale either by surface coating or by application of nanoparticles.

Learning Outcomes

Upon successful completion of this course, students will:

- Be able to know the field of tribology in nano scale.
- Be able to know the interfacial phenomena in microstructures and related instruments.
- Be able to understand the effect of surface properties in tribology
- Be able to understand friction and wear in nano scale and measurement of surface roughness.
- Be able to learn different types of nanomaterials.
- Be able to learn the preparation and characterization of nano lubricants.
- Be able to learn friction and wear behaviour of metals and non-metals

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction to nanotechnologies, Nano Tribological Phenomena, Principles and Mechanisms.	3	Introduce the students to the field of Tribology in Nano scale.
2	Significance of surfaces. Microtribology Instrumentation, Characterization of nanostructures, Low-Load Tribometers, Nanoindentation-Based Tribometers.	6	Students will learn about the fundamental understanding of interfacial phenomena in microstructures and related instruments.

3	Surface Energy and surface force: Surface tension of liquids, surface energy of solids, relation between surface force and surface energy.	4	Students will learn the effect of surface properties in tribology.
4	Nanoscale Friction, Measurement and Analysis, Friction Force Microscopy	4	Students will learn basic understanding of friction in nano scale and measurement of surface roughness, adhesion, friction, scratching, wear.
5	Nano materials: Nanoparticles, Nanotubes, Nanowires, Hybrid nanoparticles, Colloidal suspensions Nano composites, Nano sensors. Properties of nanomaterial, surface energy, wettability.	10	Students will learn different types of nanomaterials.
6	Nano fluids, lubricants and lubrication, Nano-manufacturing, nanomaterial synthesis.	6	Students will learn the preparation and characterization of nano lubricants.
7	Environmental Effects in Tribology: Metals, Ceramics, Carbon Surfaces, Solid lubricants	6	Students will learn friction and wear behaviour of metals and non-metals.

Textbooks:

1. Y.W. Chung, Micro and Nano Scale Phenomenon in Tribology, CRC Press, 2nd Ed. 2012.
2. Gabor L. Hornyak, John J. Moore, H.F. Tibbals, J. Dutta, Fundamentals of Nanotechnology, CRC Press, 1st Ed. 2008.

References:

1. Sujeet K Sinha et al., Nano-tribology and Materials in MEMS, Springer, 2013.
2. Bharat Bhushan, Nanotribology and Nanomechanics: An Introduction, Springer International Publishing, 4th Ed. 2017.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED566	**Simulation in Maintenance Engineering and Tribology**	3	0	0	9

Course Objective
To understand the different analytical and computational models to the field maintenance engineering and tribology.
Learning Outcomes

Upon successful completion of this course, students will:

- Be able to know the computational models to the field maintenance engineering and tribology.
- Be able to know the lubrication models using MATLAB.
- Be able to know the computational modelling of different Wears.
- Be able to understand simulation of failure analysis.
- Be able to learn computer simulation for different case studies related to maintenance engineering and tribology.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction to modelling and simulations in tribology and Maintenance Engineering.	2	Introduce the different analytical and computational models to the field maintenance engineering and tribology.
2	Lubrication theory, Reynolds equation, numerical methods used to solve Reynolds equation, load balance. Computer simulation for lubrication models using MATLAB.	8	Students will learn lubrication models using MATLAB.
3	Modelling of surface roughness effects. Wear models and simulation methods. Thermal effects in tribology and computer simulation. Typical results and their applicability.	9	Students will learn computational modelling of different Wears.
4	Simulation Basics related to break downs Dynamical. Finite State, and Complex Model Simulations of failures.	10	Students will learn simulation of failure analysis.
5	Probability and Statistics for Simulations and Analysis of failure events, Case study on related to break downs using MATLAB.	10	Students will learn computer simulation for different case studies related to maintenance engineering and tribology.

Textbooks

1. Y W Chung , Micro- and Nanoscale Phenomena in Tribology ,CRC, 2nd Ed.2017.
2. I.I. Kudish, M.J. Covitch, Modelling and Analytical Methods in Tribology, Chapman and Hall/CRC, 1st Ed.2010.

References

1. F.F. Ling, C.H.T. Pan ,Approaches to Modelling of Friction and Wear, springer-verlag, 1st Ed.1988.
2. K.C. Ludema, R.G. Bayer , Tribological Modelling for Mechanical Designers, ASTM, 1st Ed.1991.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	MEO 588	**Risk Analysis and Safety**	3	0	0	9

Course Objective

The objective of the course is to equip students with analytical knowledge of minimization of risks in fabrication, production and operation of products and services and associated disaster and safety management.

Learning Outcomes

Upon successful completion of this course, students will:

- Be able to understand basics of risk and safety in plants and machineries.
- Be able to learn various types of risk analyses.
- Be able to learn about human safety and disaster management
- Be able to know about safety from lubricants, safety codes and risk analysis software.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction, Typical Hazards, Tools for hazard identification and analysis in plants and machinery, Accident indices, Check lists	5	This unit will help learn basics of hazards and accidents
2	Preliminary Hazard Analysis (PHA), Failure mode and effects analysis (FMEA) and Failure mode, effects and criticality analysis (FMECA	10	This unit will help students in gaining knowledge about various hazard analyses.
3	Hazard and operability studies (HAZOP), Fire and explosion hazards, Dow's fire and explosion index, Hazard analysis-Fault tree analysis (FTA)	8	Understanding of specific analyses in plants and machineries.
4	Event tree analysis (ETA), Cause consequence analysis (CCA), Mathematical models for cause consequence analysis, Risk evaluation and acceptance criteria	8	This unit will help students in learning about analytical models of hazards and their evaluation.

5	Human factors in safety, safety management, Disaster management plan	4	This unit will help students in learning about human safety and disaster management
6	Safety aspects of lubricants, Safety codes, Case studies, SHE /Velocity EHS Software	4	This unit will help students to learn about safety from lubricants, safety codes and risk analysis software.

Textbooks

1. Reliability Engineering and Risk analysis - A practical guide : Mohammad Modarres, Mark P. Kaminskiy and Vasiliy Krivtsov (2016). 3rd Edition CRC Press Boca Raton
2. System Safety Engineering and Risk Assessment: A Practical Approach, Second Edition Nicholas J. Bahr20172nd Edition CRC Press.

Reference standards/software

3. ISO 45001:2018 Occupational Health And Safety Management Systems
4. Risk Assessment SHE / Risk Analysis Velocity EHS Software

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	MEO 589	**Maintenance Audit**	3	0	0	9

Course Objective
The objective of the course is to impart knowledge of maintenance audit of plants and machineries to students in order to help industries solve associated expenses and improvement. .
Learning Outcomes

Upon successful completion of this course, students will:

- Be able to understand basics of maintenance audit
- Be able to learn about collection and analysis of data.
- Be able to learn about interpretation and reporting of data for improvement of maintenance activities.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction: A Methodology for auditing the industrial maintenance function. The purpose and procedures of such auditing. An outline with examples of a full audit, a snapshot audit and a fingerprint audit.	11	This unit will help learn basics of maintenance audit and associated activities.
2	Data Collection: Information gathering strategy : Information gathering techniques: models, questionnaires, survey forms. An outline of an aide-memoire based on the audit methodology Methods of interviewing	8	This unit will help students in collection of data by different methods.
3	Data Analysis: Analysis of data, the analysis procedure, identification of problem areas, developing improved organizations and systems.	8	Understanding of analysis of data of maintenance.
4	Reporting: The report structure, the audit section, the proposal section. Discussion and analysis of actual audit reports. Audit data to identify problems, their causes and solutions.	12	This unit will help students in the interpretation and reporting of data for improvement.

Text Books

1. Maintenance Audits Handbook: Diego Galar Pascual, Uday Kumar, CRC Press; 1 edition 2016
2. Maintenance Management Audit: Hervey H. Kaiser, R S Means Co; Spiral edition 1992

References book

3. Auditing the Maintenance of Software: Vallabhaneni S Rao

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	**MEO582**	**Flow and Transport Phenomena Through Piping System**	3	0	0	9

Course Objectives
1. To study transport of fluids in pipe. 2. To study about the components of piping system. 3. To study different application of piping system in agriculture, drainage, drinking and other industry applications.
Learning Outcomes
Upon successful completion of this course, students will: 1. have a broad understanding about fluids properties flowing through pipeline and transport theory. 2. have an understanding about the application of piping system in different field. 3. be able to use soft techniques to solve fluid distribution problem through pipe network. 4. be able to understand reasons behind erosion and corrosion occurred in pipeline and their remedy

Modules	Topics	Lecture hours	Learning outcomes
1	Basic Concepts: Conservation of mass, energy, momentum, second law of thermodynamics, unit and dimensions, fluid properties in perspective.	6	Understanding basic concept of fluid properties and laws of thermodynamics.

2	Introduction to Transport phenomenon, Momentum transport: Viscosity and mechanisms of Momentum transport, velocity distribution in laminar and turbulent flow, Energy Transport, Mass Transport.	9	Understanding the transport phenomenon through pipe.
3	Transport of fluids in piping system: pipe flow, noncircular conduits, economic pipe diameter, various fittings, Non-Newtonian fluids, pumps and compressors, pipe network problems. Solve pipe network problem using BENTLEY HAMMER software.	9	Understanding piping system components and their design aspects.
4	Applications: Pipelines for water conveyance and drainage: Materials, Specifications and industry standards, Available sizes, system of units, corrosion, Fluid and Gas in Pipelines: Governing Factors, Slurry Transport: Rheometry and Rheological Models, Turbulent Flow of Non-Newtonians, Effects of Solids Concentration, Heat pipes: heat transfer and fluid flow theory.	9	Understanding different application of piping system in agriculture/drainage/industry, etc, and the flow characteristics.
5	Thermodynamics of corrosion. Fundamentals and application of corrosion theories, interaction of corrosion with erosion. Corrosion Control- Design improvement.	6	Understanding different problems arises due to flow in pipeline and the remedies.

Text Books:

1. Ron Darbyand, Raj P. Chhabra, Chemical Engineering Fluid Mechanics, CRC Press; 3rd Edition, 2016.

References:

2. Bird, R. B., Stewart, W. E., Lightfoot, E. N. and Klingenberg, D. J., Introductory Transport Phenomena, Wiley, 2015.

3. Christie J. Geankoplis, Transport process and unit operations, Prentice-Hall International, University of Minnesota, 3rd Edition, 1993.

4. Bird, Stewart, Lightfoot, Transport Phenomena, Wiley, 2nd Edition, 2002.

5. W. M. Deen, Analysis of Transport Phenomena, Oxford University Press, 2nd Edition, 2012.

6. E. L. Cussler, Diffusion: Mass Transfer in Fluid Systems, 3rd Edition, 2009.

COURSE WORK IN THERMAL ENGINEERING

MONSOON SEMESTER

Course No.	**Course Name**	Semester	**L**	**T**	**P**	**CH**
MEC502	Numerical Methods	1st	3	0	0	9
MEC507	Incompressible and Compressible Flow	1st	3	0	0	9
MEC508	Advanced Heat Transfer	1st	3	0	0	9
MEC591	Research Methodology and Statistics	1st	3	0	0	9
HSI500	Research and Technical Communication	1st	3	0	0	9

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	**MEC507**	**Incompressible and Compressible Flow**	3	0	0	9

Course Objectives
1. To broaden the perspectives of fluid dynamics that the students were introduced to in their first level undergraduate course of Fluid Mechanics. 2. To introduce new and advanced topics in details to the students that will increase their curiosity, improve their ability to explain fluid flow through physics supported by mathematical analysis besides enhancing the understanding of theoretical fluid dynamics.
Learning Outcomes
1. Students will be writing or expanding differential equations using indicial notations. This will certainly help them in their journey through research papers during the Masters research. 2. Strong foundation of the viscous, incompressible flow equations and their forms. 3. Understanding of the close coupling between Fluid Mechanics and Thermodynamics.

Modules	Topics	Lecture hours	Learning outcomes
1	Generalized curvilinear coordinates, Introduction to tensors	2	To express a given differential equation in generic form independent of coordinate system. This generic form is also brief in appearance

2	Reynolds Transport Theorem (RTT), derivation of the continuity and momentum equations, the conservation equations in vector and tensor forms, conservation equations in Cartesian, cylindrical polar and spherical polar coordinates	4	Bridging the particle and point approaches of mechanics, express any conservation equation using vector or tensor notations, express the conservation equations in various alternate forms, i.e. conservative, non-conservative, stress-divergence, etc
3	Analytical solutions of Navier-Stokes equations of motion	2	To identify the scant cases of viscous flow where closed form solutions of momentum equations are possible. Simplification of full Navier-Stokes equations under these special cases
4	The concept of boundary layer, Prandtl's boundary layer theory and its limitations, boundary layer equations over a flat plate at zero incidence and similarity solution by Blasius, momentum integral equation, Karman-Pohlhausen method, separation of boundary layer	6	To perform scale analysis and reduce a differential equation to its simplified form, identify similarity variable and perform similarity solution, numerically solve a non-linear ODE, explain fluid forcing based on separation phenomenon
5	Forces on immersed bodies – drag and lift	2	Calculation of global fluid force from distributed fluid forces over a surface, to explain the contributions of surface pressure, body shape and separation points in controlling fluid loading
6	Transition to turbulence, concepts of turbulence modeling, space and time scales of turbulence, space correlation and cross-correlation, Reynolds form of the continuity and momentum equations.	5	To distinguish between the laminar and turbulent flows with further depth and insight, to familiarize with the basic approximate equations employed in analyzing turbulence
7	Compressible Flow, Thermodynamic relations of Perfect gases, Stagnation properties	2	Students will have clear idea of the coupling of compressible fluid flow with the fundamentals of thermodynamics

8	Isentropic flow with variable area duct and Flow with normal shock waves	5	Ability to distinguish between pure one-dimensional and quasi-one dimensional flows. Understanding of the normal shock theory
9	Supersonic wind tunnels, Flow with oblique shock waves, oblique shock relations from normal shock equations, Mach waves	8	Understanding of the oblique shocks as well as thermodynamic relations of oblique shocks
10	Flow in constant area ducts with friction and flow with heat transfer	3	Control volume treatment of one dimensional Rayleigh-line and Fanno line flow

Text Books:

1. F. M. White, Viscous Fluid Flow, McGraw-Hill, New York, 2nd Edition, 2012.

2. Philip J. Pritchard and John W. Mitchell, Introduction to Fluid Mechanics, Fox and McDonald's, John Wiley & Sons, 9th Edition, 2016.

References:

3. R. L. Panton, Incompressible Flow, John Wiley & Sons, 4th Edition, 2013.

4. H. Schlichting, Boundary Layer Theory, Springer, 8th revised Edition, 2001.

5. W. Yuan, Foundation of Fluid Mechanics, PHI, S.I. unit Edition, 1988.

6. V. Babu, Fundamentals of Gas Dynamics, Wiley-Blackwell, Chennai, 2nd Edition, 2015.

7. P. H. Oosthuizen and W. E. Carscallen, Compressible Fluid Flow (Engineering Series), McGraw-Hill Science/Engineering/Math, 1st Edition, 2003.

8. S. M. Yahya, Fundamentals of Compressible Flow with Aircraft and Rocket Propulsion, New Age International, 2018.

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	**MEC508**	**Advanced Heat Transfer**	3	0	0	9

Course Objectives
This course is designed to make the student understand the basic principles of heat and mass transfer, and to develop methodologies for solving wide varieties of practical engineering problems.
Learning Outcomes
Upon successful completion of this course, students will: 1. have a broad understanding of advanced topic of heat transfer. 2. have analytical and mathematical tools to handle complex heat transfer problem. 3. be able to provide some basic solution to real life heat transfer problems.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction to Conduction, convection and radiation heat transfer, 1-D Steady State Heat Conduction, Heat conduction in non-isotropic materials, Fins with variable cross-section, Moving fins. Conduction shape factor, Multi-dimensional steady state heat conduction, Graphical Method: (The Schmidt Plot)	5	Students will review the basic heat transfer. They will learn about steady state conduction and its application

2	Improved lumped models, Duhamel's superposition integral. Transient heat flow in a semi-infinite solid: The similarity method, The integral method	5	Transient heat conduction and its analysis will be learned
3	Heat equation for moving boundary problems, Stefan's solution. Moving Heat Sources	4	Specific topics discussing about moving boundary problem will be analyzed
4	Momentum and Energy Integral Equations, Thermal ad hydrodynamic boundary layer thickness, Heat transfer in a circular pipe in laminar flow when constant heat flux and constant wall temperature to the wall of the pipe, convection correlations for turbulent flow in tubes, Flow over cylinders and spheres, Flow across tube bundles/banks. Heat transfer from a vertical plate using the Integral method	10	Student will be able to understand convection heat transfer. They will be able to analyze the problem mathematically and relate it to real life example
5	Free convection in enclosed spaces, Mixed convection, High speed flows	5	Students will be able to differentiate between forced and free convection. They will also learn to analyze the mixed convection problems
6	Radiation heat transfer, View factors: Cross string method, unit sphere and inside sphere method, Radiant energy transfer through absorbing, emitting and scattering media, Radiative transfer equation, Enclosure analysis in the presence of an absorbing or emitting gas	6	Students will be able to analyze the radiation heat transfer
7	Heat exchangers	4	Students will understand the importance of heat exchanger and its use in process industries
Text Books:			

1. F. Incropera and D. J. Dewitt, Fundamentals of heat and mass transfer –Wiley & Sons Inc., 7th Edition, 2011.

Reference Books:

2. K. Muralidhar and J. Banerjee, Conduction and Radiation, 2nd Edition, Narosa, 2010.
3. Latif M. Jiji., Heat Conduction, Springer, 3rd Edition, 2009.
4. A. Bejan, Convective Heat Transfer, J. Wiley & Sons, 3rd Edition, 2004.
5. M. F. Modest, Radiative Heat Transfer, Academic Press, 3rd Edition, 2013.

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	**MEC591**	**Research Methodology and Statistics**	3	0	0	9

Course Objectives
To illustrate to the students a) the basic concepts of research, b) how a scientific research problem has to be formulated and tackled and c) important statistical tools necessary to analyze the collected data for a meaningful research outcome.
Learning Outcomes
Upon successful completion of this course, students will: 1. learn various types of research process, methodologies to identify, design and execute a research problem based on scientific and statistical tools. 2. learn various types of sample design techniques and its classification, characteristics of a good sample design and how to select a sampling procedure for data collection. 3. learn various types of measurement scales, sources of error in measurement and technique of developing measurement tools to evaluate the collected data. 4. learn various methods of data collection and the reliability and validity of the collected data. 5. learn various ways to prepare and present report for dissemination of research outcome. 6. learn various statistical tools necessary for designing a sample, analyzing the data and making scientific conclusion(s) out of the collected data to arrive at a research outcome.

Modules	Topics	Lecture hours	Learning outcomes

1	Research Process, Types of Research, Problem identification, Hypotheses formulation	5	Basic ideas on research processes, Definition of various types of research, Knowledge on what constitute a research and how to identify a research problem, Knowledge on the formulation of hypothesis for research
2	Research Design: General Designs of Research, Randomized and Correlated Groups Design	5	Meaning of research design, Ideas on the need for research design, Knowledge on the features of a good research problem design, Important concepts relating to research design, Ideas on different research design methodologies, Ideas on the basic principles of experimental designs.
3	Sampling Design, Measurement and Scaling, Methods of Data Collection, Reliability and Validity	5	Ideas on the Implications of a Sample Design and its classification, Knowledge on the criteria of selecting a sampling procedure and characteristics of a good sample design, Ideas on measurement scales and sources of error in measurement, Knowledge on technique of developing measurement tools, Ideas on the meaning of scaling and important scaling techniques, Ideas on the methods of data collection and the reliability and validity of the collected data.
4	Data Presentation and Report Preparation, Introduction to Qualitative and Quantitative Research Methods	3	Ideas on Data presentation and report preparation techniques, Sensitizing the students on the very important issues of plagiarism, Preliminary ideas on the qualitative and quantitative research methodologies and their mutual difference.
5	Frequency Distribution, Presentation of Data, Measures of Central Tendency, Measures of Dispersion, Skewness	3	Ideas and knowledge on frequency distribution, cumulative frequency distribution, constructing histograms, Knowledge on the measures of central tendency (Mean, Median and Mode), Various measures of dispersion of the data.

6	Probability Distributions, Discrete and continuous random variable, Binomial, Poisson, Normal and Standard Normal distributions	6	Learn about Experiment, Outcomes, and Sample Space, Calculation of Probability, Ideas on Marginal and Conditional Probabilities, Learn about Mutually Exclusive, Independent and Complementary Events, Learn about Bay's Theorem, Learn about discrete and continuous random variables and how to calculate their mean and standard deviation, Learn about Binomial, Poisson, Normal and Standard Normal distributions.
7	Sampling and Estimation, Sampling Distribution, Estimation of the mean and proportion, Hypothesis tests about the mean and proportion of a population, t-test and z-test, Estimation and hypothesis testing about two different populations.	6	Learn about sampling and estimation methods, hypothesis testing regarding the properties of the population from the sample statistics (sample mean and variance), Learn about Student's t-distribution and z-distribution and t-test and z-tests, Knowledge on estimation and hypothesis testing about two different populations
8	Hypotheses testing: □□ test, Analysis of Variance, Correlation and Regression analysis.	6	Learn about the Chi-Square distribution, Goodness-of-Fit test, Learn about making contingency tables, Learn about testing independence or homogeneity of populations, Learn to infer about the population variance, F-Distribution and one-way ANOVA, Learn about simple linear regression models and analysis.

Text Books:

1. Research Methodology - Methods and Techniques, C. R. Kothari and G. Garg, New Age International (P) Limited Publishers, 4th Edition, 2019, New Delhi.
2. Applied Statistics and Probability for Engineers, D. C. Montgomery and George C. Runger, 6th Edition, 2016.

References:

3. Research Methodology: A Step-by-Step Guide for Beginners, R. Kumar, SAGE Publications Ltd; 5th Edition, 2018.
4. Introductory Statistics, Prem S. Mann, 7th Edition, John Wiley and Sons Inc., 2010, Danvers, MA.

WINTER SEMESTER

Four elective courses from Winter Semester

	PG Level Courses	Semester				
Course No.	**Course Name**		**L**	**T**	**P**	**CH**
MED538	Gas Dynamics	2nd	3	0	0	9
MED539	Fundamentals of Aerodynamics	2nd	3	0	0	9
MED540	Fundamentals of Aeroacoustics	2nd	3	0	0	9
MED541	Microfluidics	2nd	3	0	0	9
MED542	Finite Element Method in Thermal Engineering	2nd	3	0	0	9
MED543	Solar Energy	2nd	3	0	0	9
MED544	Advanced Steam Power Plant	2nd	3	0	0	9
MED545	Turbomachinery	2nd	3	0	0	9
MED546	Conduction and Radiation	2nd	3	0	0	9
MED547	Convection and Two-Phase Flow	2nd	3	0	0	9

MED548	Heat Exchanger Design	2^{nd}	3	0	0	9
MED549	Cryogenic Engineering	2^{nd}	3	0	0	9
MED550	Combustion and Emission in I.C. Engines	2^{nd}	3	0	0	9
MEO579	Computational Fluid Dynamics	2^{nd}	3	0	0	9
MEO580	Measurements in Thermal Engineering	2^{nd}	3	0	0	9
MEO581	Fundamentals of combustion	2^{nd}	3	0	0	9
MED573	Advanced Optimization Techniques	4^{th}	3	0	0	9
MEO 582	Flow and Transport Phenomena Through Piping System	4^{th}	3	0	0	9
MEO 583	Design of Thermal systems	4^{th}	3	0	0	9
MEO 584	Waste Heat Utilization	4^{th}	3	0	0	9

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED538**	**Gas Dynamics**	3	0	0	9

Course Objectives
1. The aim of the course is to lay out the basic concepts and results for the compressible flow of gases. 2. Students can apply the principles of gas dynamics for the design of high speed vehicles, such as rockets, missiles and high speed aircraft.
Learning Outcomes
Upon successful completion of this course, students will: 1. have a broad understanding of the basic concepts of gas dynamics. 2. have a thorough understanding of Mach waves, shock waves and their relations. 3. be able to apply the principles of gas dynamics for predicting the aerodynamic characteristics of the in high speed vehicles.

Modules	Topics	Lecture hours	Learning outcomes
1	Review of Fundamentals: Concepts from Fluid Mechanics, Compressibility Thermodynamic concepts, Conservation equations, Stagnation state	4	To understand the basic concepts and elements of compressible flow
2	Compressible flow: Concept of Waves in fluid, Mach waves, Compression waves, Expansion fans, Differential equations for 1D flow	4	To understand the concepts of Mach waves, Compression waves, Expansion fans and differential equations for 1D flow

3	Basic Flow features: Isentropic flow, Shock waves, Stationary and Moving Shocks, Oblique Shocks, Bow Shocks, Expansion Fans, Normal Shock Concept, Normal Shock relations, Moving normal shocks Concept and theory, Oblique Shock relations, Property variations	7	To understand the concepts of a shock wave, stationary and moving, Normal and oblique shocks, Normal/Oblique shock relations
4	Detached Shocks, Shock Reflections, Flow around bodies, Crocco's theorem, Cone flows, Shock expansion theory	7	To understand the concepts of detached shocks, shock reflections, Cone flows and shock expansion theory
5	Quasi-1D flow with area variations, Geometric Choking, Convergent Nozzles, CD Nozzles, Exit vs Stagnation pressure variation, shock wave reflections, Jet flows, Under expanded and over-expanded jet flows, Flow with Friction, Friction choking, Flow with heat addition, Thermal choking	10	To understand the concepts of QUASI-1D flows, Under expanded and over-expanded jet flows, Flows with friction and Flows with heat transfer
6	Prandtl Meyer Function, Supersonic wind tunnel, Shock Tube, Shock tunnel, Flow visualization, Basics of hypersonic flow	7	To understand the concepts of supersonic wind tunnel, Shock Tube and Shock tunnel

Text books:

1. Liepmann, H. W. and Roshko, A., Elements of Gas Dynamics, Dover Publications Inc., 2002.

2. John D. Anderson, Modern Compressible Flow: With Historical Perspectives, 3rd Edition, 2004.

References:

3. Oosthuizen, P. H. and Carscallen, W. E., Compressible Fluid Flow, McGraw-Hill international Edition, Singapore, 1st Edition, 2003.

4. Babu, V., Fundamentals of Gas Dynamics, Wiley-Blackwell, 2nd Edition, 2014.

5. Chapman A. J. and Walker W. F., Introductory Gas Dynamics, Holt, Reinhart and Winston, Inc., NY, USA, 1st Edition, 1971.

6. S. M. Yahya, Fundamentals of Compressible Flow with Aircraft and Rocket Propulsion, New Age International, 2018.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED539**	**Fundamentals of Aerodynamics**	3	0	0	9

Course Objectives
To illustrate and explain to students the basics principals and governing conservation equations and how these fundamentals can be applied to estimate aerodynamic forces and moments and to understand other related interesting problems.
Learning Outcomes
On successful completion of the course, the students will 1. Learn the fundamental principles of fluid mechanics and thermodynamics required to investigate the aerodynamics of airfoils, wings, and airplanes and other related problems; 2. Learn about the geometric features of airfoils, wings, and airplanes and how the names for these features are used in aerodynamics communications; 3. Explore the aerodynamic forces and moments that act on airfoils, wings, and airplanes and learn how we describe, estimate and compute numerically and theoretically these loads quantitatively in dimensional form and as coefficients; 4. Learn the reason behind induced drag and the formation of trailing edge vortices for a 3D finite wing and its relevance in other related problems occurring in nature; 5. Learn about the effects of compressibility, formation of shocks and expansion fans on the aerodynamic performances of streamlined, bluff bodies and the jet exhaust.

Modules	Topics	Lecture hours	Learning outcomes

1	Basic overview of aerodynamics; Aerodynamic forces and moments; Continuity, Momentum and Energy equations; Inviscid incompressible flow; Applicability of the Bernoulli's equation	5	Understanding of the basic overview of Aerodynamics, Ideas on aerodynamics moments and forces, Derivation on the continuity and momentum and energy equation, Ideas on the basics of inviscid incompressible flows, flow features, Ideas on the application of Bernoulli's equation
2	Incompressible flow in a low speed wind tunnel, Potential flows with source and doublet, Potential flow over a circular cylinder, Kutta-Joukowski theorem and conformal mapping	4	Basic ideas on the characteristics of the incompressible flow in a low-speed wind tunnel, Ideas on sources and doublets and their application to the potential flow over a circular cylinder, Ideas on Conformal Transformation and Kutta-Jukowski Theorem and its application to estimate the lift coefficient of a 2D airfoil section
3	Incompressible flow over airfoils and finite wings, Kutta condition, Kelvin's circulation theorem, Biot-Savart law, Helmholtz vortex theorem	5	Ideas on the incompressible flows over airfoil, The effects of finite wing, Ideas on downwash as a consequence of wing-tip vortex, Estimation of induced drag, Applicability of the Kutta-condition to fix the condition on the trailing edge, Ideas on the Kelvin's circulation theorem, Biot-Savart law and Helmholtz Theorems
4	Thin aerofoil theory; Prandtl's classical lifting line theory; Three dimensional source and doublet	7	Derivation of the thin airfoil theory and Prandtl's lifting line theory, Uses of these theories to estimate dependence of lift coefficient on the angle of attack, Introduction to the 3D source and doublet and extension of the 2D potential flow to 3D flow cases
5	Inviscid compressible flow, normal and oblique shocks, expansion waves, supersonic wind tunnels	7	Ideas on the inviscid compressible flow, normal and oblique shocks and Prandtl Meyer expansion fan and their reflection, General idea on the operational principals of supersonic wind-tunnel
6	Elements of hypersonic flow, Newtonian theory; Equations of viscous flow; Laminar and turbulent	4	Ideas on the elements of hypersonic flows and Newtonian theory, Ideas on the equations of viscous flow, Basic

	boundary layers		concepts on the laminar turbulent transition in a boundary layer
7	Panel methods in aerodynamics, Flow separation and control, Jet flow and mixing layer	7	Ideas on the panel methods to estimate lift coefficients for arbitrary shaped bodies based on Potential flow theory, Basic ideas on flow separation and control, Jet flow and mixing layer

Text Books:

1. J. D. Jr. Anderson, Fundamentals of Aerodynamics, McGraw- Hill , 6th Edition, 2016.

References:

1. J. J. Bertin, Aerodynamics for Engineers, Pearson Education, 4th Edition, 2002.

2. E. L. Houghton and N. B. Carruthers, Aerodynamics for Engg. Students, Arnold Pub., 3rd Revised Edition, 1988.

3. A. M. Kuethe, and C. Y. Chow, Foundations of Aerodynamics, Wiley, 5th Edition, 1998.

4. L. J. Clancy, Aerodynamics, Himalayan Books, 1st Edition, 2006.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED540**	**Fundamentals of Aeroacoustics**	3	0	0	9

Course Objectives
1. To understand the basics of flow induced noise via turbulent fluid motion / aerodynamic forces interacting with the surfaces since the area of aeroacoustics is an emerging one throughout the world. 2. It provides motivation to the students for pursuing higher studies / career related to aeroacoustics since many industries, universities and R&D sectors are working towards noise control.
Learning Outcomes
Upon successful completion of this course, students will: 1. have a broad understanding of basic concepts of aeroacoustics, governing equations. 2. have a thorough understanding of various noise sources, sound generation by flow. 3. be able to apply Lighthill's acoustic analogy, Ffowcs Williams and Hawking's theory for predicting the far-field acoustic radiations.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction: Background and definition of aeroacoustics, Linearity of acoustics, acoustics, vortical and entropy waves	4	To understand the background and definition of aeroacoustics, Linearity of acoustics

2	Conservation equations, Governing equations for 1-D and 3-D acoustics, Helmholtz resonator, Acoustic energy, intensity, Fourier analysis, power spectrum	4	To understand the Governing equations for 1-D and 3-D acoustics, Basic principle of Helmholtz resonator, Fourier analysis
3	1-D and spherically-symmetric acoustics in a medium at rest, Helhmholtz equation, Sound field due to monopole, dipole and quadrupole sources, their importance and relation with oscillating spheres	5	To understand the various sound sources, Helhmholtz equation
4	Green's function for wave equation, Green's formula, far-field approximations, compact sources and interferences	7	To understand the compact acoustic sources, far-field approximations
5	Acoustics of rigid solid boundaries: reciprocity theorem, Kirchhoff's formula, Analysis of sound due to moving sources	5	To understand the concepts reciprocity theorem, Kirchhoff's formula
6	Sound generation by flow: Lighthill's acoustic analogy, Ffowcs Williams and Hawking's theory	7	To understand the concepts of Lighthill's acoustic analogy and Ffowcs Williams and Hawking's theory for the predictions of flow induced noise
7	Interaction tones, buzz-saw noise, Aeolian tones: cavity noise, Experimental aeroacoustics: Anechoic chamber, calibration procedure, acoustic sensors, aero-acoustic measurements	7	To understand the concepts tonal and broadband noise, some basics of anechoic chamber, calibration procedure of anechoic chamber, aeroacoustic measurement techniques

Text books:

1. Goldstein, M. E., Aeroacoustics, McGraw-Hill, 1976.

2. Mueller, Thomas J. (Ed.), Aeroacoustic Measurements, Springer-Verlag Berlin Heidelberg, © 2002.

References:

3. Crighton, D. G., Basic principles of aerodynamic noise generation, Prog. Aerospace Sci., 16(1), 1975, pp. 31-96.

4. Howe, M. S., Theory of vortex sound, Cambridge University Press, 1st Edition, 2002.

5. Pierce, A. D., Acoustics, Acoustical Society of America, 1st Revised Edition, 1989.

6. Crighton, D. G., Dowling, A. P., Ffowcs Williams, J. E., Heckl, M. and Leppington, F. G., Modern methods in analytical acoustics, Springer, 1st Edition, 1992.

7. L. E. Kinsler, A. R. Frey, A. B. Coppens and J. V. Sanders, Fundamentals of Acoustics, John Wiley, 4th Edition.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED541**	**Microfluidics**	3	0	0	9

Course Objectives
Microfluidics is an emerging and rapidly growing technology. The concept is widely applied to thermal management; MEMS based instruments and biological devices. In this course, students will learn principles of micro- and nano-scale transport phenomena. In addition, the course will also discuss about the micro-fabrication and few components of micro-system with some application.
Learning Outcomes
Upon successful completion of this course, students will: 1. have a broad understanding of microfluidics and its application. 2. have analytical and mathematical tools to handle microfluidics problem. 3. be able to understand the fabrication technique for making microfluidics devices.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction to microfluidics; Scaling analysis	3	Students will learn about the basics of microfluidics and its comparison with macro level fluid mechanics
2	Theory of microscale fluid flow: Intermolecular forces, States of matter, Continuum assumption, Governing equations, Constitutive relations. Gas and liquid flows, Boundary conditions, Slip theory, Transition to turbulence, Low Re flows,	12	They will learn the basic fluids mechanics and mathematic used for the analysis of microfluidics.

	Entrance effects. Exact solutions, Couette flow, Poiseuille flow, Stokes drag on a sphere, Time-dependent flows, Two-phase flows, Thermal transfer in microchannels. Hydraulic resistance and Circuit analysis, Straight channel of different cross-sections, Channels in series and parallel		
3	Micro fabrication: Fabrication techniques for microdevices: photolithography, silicon-based micromachining, polymer-based micromachining	9	Students will learn about the different fabrication techniques for microfluidics devices
4	Components of microsystems- micropump, microvalve, micromixer, microparticle separator; Thermal transfers in microdevices; Micro- heat exchangers; Issues and challenges in microfluidic devices; Sensors and actuators; Biomicrofluidics, Lab-on-chip devices; Micro-total-analysis systems (μ-TAS)	12	In this module different microfluidics devices and their working will be discussed
5	Few applications of microfluidics: Drug delivery, Diagnostics, Bio-sensing	3	Recent applications of microfluidics for bio application will be discussed

Text Books:

1. Nguyen, N. T., Werely, S. T., Fundamentals and applications of Microfluidics, Artech House; 3rd Edition (January 31, 2019).

References:

2. Madou, M. J., Fundamentals of Microfabrication, CRC press.
3. Tabeling, P., Introduction to microfluidics, Oxford University Press Inc.
4. Kirby, B. J., Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED542**	**Finite Element Method in Thermal Engineering**	3	0	0	9

Course Objectives
1. FEM is going to be an indispensable numerical tool in the near future. The primary objective of this course is to acquaint the students with this powerful numerical method that enables them to solve simple as well as complex fluid dynamics and heat transfer problems with high accuracy. 2. To highlight the differences in FEM treatment of solid mechanics (Galerkin based) and fluid dynamics (Petrov-Galerkin based) problems.
Learning Outcomes
1. The students will develop the ability to model steady/unsteady heat conduction as well as convection-diffusion problems using FEM. 2. Relative to the conventional FEM ways of generating the assembled matrix and vector, the students will learn a different approach of formulating the global matrix and vector that is very conducive to computer coding. 3. According to the present curriculum, this course will be offered simultaneously with Computational Fluid Dynamics where FDM and FVM are mostly covered. After this FEM course, the connections/differences among these three compteting numerical tools will be very clear to the students.

Modules	Topics	Lecture hours	Learning outcomes
1	Concept of variational methods, concept of FEM, comparison with alternate methods such as, FDM and FVM	7	This introductory module will enable the students to have the basic flavour of early numerical methods that were developed as a suitable substitute of the analytical approach

2	Strong and weak forms of a differential equation, Galerkin finite-element method, weight and shape functions, element connectivity and assembly	5	After this module, the students will be able to generate the variational statement of a given PDE or ODE. Besides, they will be able to construct the basis functions and various arrays that aid in generating the global matrix and vector
3	Numerical integration, isoparametric elements, coordinate transformation, basic matrix equation solvers	6	This foundation module will enable the students to evaluate the element level matrix and vector entries via Gauss quadrature. The strength of FEM for problems involving complex geometry will be more apparent. This module will also familiarize the students with the role of linear algebra in solving fluid dynamics problems via FEM
4	FEM discretization of unsteady equations, implicit and explicit methods, implementation of EBC, NBC and convective boundary conditions	4	The students will be familiar with the trapezoidal rule to discretize an unsteady term via FDM. They will also learn to implement the boundary conditions via use of various arrays discussed in module II
5	Matrix and vector formation for one- and two-dimensional heat conduction problems, treatment of one-dimensional convection-diffusion equation using linear and quadratic elements	7	This module implements for a single-degree-of-freedom problem, the theory discussed in the previous modules. The students will be able to completely formulate and discretize the Laplace/Poisson equations in single or two-dimensions and one-dimensional convection-diffusion equation
6	Limitations of Galerkin method for flow problems, upwinding, Petrov-Galerkin method, Navier-Stokes equations: properties and limitations, coupled versus segregated formulation of Navier-Stokes equations,	5	This module will highlight the inability of the Galerkin formulation to accurately predict a flow field and will also suggest the ways to modify the Galerkin approach. The

	connectivity and assembly for equations with multiple degrees-of-freedom		students will be able to generate the global matrices for problems with multiple unknowns
7	Coupled formulation of steady Navier-Stokes equations in two-dimensions using collocated arrangement.	5	After this conclusive module, the students are expected to successfully discretize the Navier-Stokes equations of motion using coupled approach in two-dimensions

Text books:

1. An introduction to the finite element method, J. N. Reddy, Tata McGraw-Hill Edition, 4th Edition, 2019.

2. Finite element method for flow problems, J. Donea and A. Huerta, Wiley publication, 2003.

References:

3. The finite element method, T. J. R. Hughes, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, Dover Publications, 1st Revised Edition, 2000.

4. Fundamentals of the finite element method for heat and fluid flow, R. W. Lewis, P. Nithiarasu and K. N. Seetharamu, John Wiley & Sons, 2nd Edition, 2016.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED543**	**Solar Energy**	3	0	0	9

Course Objectives
Students can utilize the knowledge of this theoretical concept in solar based industries for manufacturing the collectors for capturing more and more energy from the Sun.
Learning Outcomes
Upon successful completion of this course, students will: 1. be able to design the flat plate solar air / water heater. 2. be able to design focusing type solar collector. 3. be able to use this solar energy concept for designing solar storage systems.

Modules	Topics	Lecture hours	Learning outcomes
1	Need of sources of renewable energy, Introduction to different sources of renewable energy, Solar Energy and Applications	3	Students will learn about renewable sources of energy
2	Basic concepts, Solar constant, Beam and diffused radiation	3	For understanding further topics, knowledge of solar constant is very important for the students

3	Flat plate and concentrating collectors, Liquid Flat Plate Collector, Flat Plate Solar Air Heater, Concentrating Collectors	8	Knowledge of different types of solar collectors are very important for capturing solar energy
4	Performance analysis of solar collector, Instantaneous collector efficiency	5	Collector efficiency is one of the important performance parameters for the solar collectors. Students will learn this terminology
5	Overall loss coefficient, Collector efficiency factor, Collector heat removal factor	4	Students will learn different losses during collection of energy through solar collectors
6	Concentration ratio, Tracking requirements, Thermal energy storages, Solar pond	10	Students will learn about concentrating solar collector. Also, they will learn about the storage the solar energy
7	Economic Analysis	4	Economics of solar energy utilization
8	Case studies: Performance test on CPC and Flat Plate collector	2	Students will do some case studies by conducting the experiments on CPC and Flat plate collector

Text books:

1. S. P. Sukhatme, Solar Energy - Principles of Thermal Collection and Storage, TMH, 3rd Edition, 2008.

References:

2. John A. Duffie and William A. Beckman, Solar Engineering for Thermal Process, Wiley and Sons, 1st Edition, 2013.

3. H. P. Garg, Solar Energy, 1st Revised Edition, 2000.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED544**	**Advanced Steam Power Plant**	3	0	0	9

Course Objectives

1. To impart knowledge dealing with computation aspects of Advanced Steam Power Plant.
2. This course is essential for design of Thermal power plant.

Learning Outcomes

1. Illustrate the fundamental principles and applications of thermal power plant system.
2. Obtain heating capacity, output power and efficiency by conducting test on vapour cycles.
3. Present the properties, applications and environmental issues of different coal.
4. Calculate performance at different loads for thermal power plant systems used for various applications. Operate and analyze the thermal plants.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction: Energy sources and scenario	2	Students will know the use of thermal properties in engineering and other applications
2	Power Plant Cycles – Reheat and Regenerative	10	An ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political ethical health

3	Supercritical – Coupled and Combined Cogeneration Plants	6	An ability to design a system and improve the output power of the thermal power plant
4	Exergy Analysis of Power Plant Cycles	2	An ability to identify, formulate and utilize maximum amount of energy
5	Coal, its properties and combustion	4	The understanding of coal properties and relative technical term combustion in thermal power plant
6	Analysis and seizing of Power Plant Components: Steam generator, Condenser, Cooling tower and other heat exchangers	7	Calculations of heating and cooling load, sensible heat and lateral heat in thermal power plant involve the usage of property equations framed earlier
7	Power plant economics and Energy audit	4	Known about the economics of the thermal power plant with relative the mathematical equation
8	Recent trends in Power Production	4	An ability to identify and formulate the thermal power plant in the current scenario

Text Books:

1. Principle of Energy Conversion by A. W. Culp, Tata McGraw-Hill.

2. Power Plant Technology by M. M. Elwakil, Tata McGraw-Hill.

References:

3. Applied Thermodynamics by T. D. Eastop and A. McConkey, ELBS.

4. Modern Power Plant Engineering by J. Weisman and R. Eckart, Prentice Hall.

5. Power Plant Engineering by P. K. Nag, Tata McGraw-Hill.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED545**	**Turbomachinery**	3	0	0	9

Course Objectives

1. To make the students accustomed with various turbomachines and related complex processes.
2. The provide knowledge of performance evaluation, operation and maintenance of rotodynamic machines.

Learning Outcomes

1. Knowledge of transport processes through the turbomachine passage.
2. Knowledge about the analytical, numerical and experimental tools for design, operation, performance evaluation.
3. Enabling the students to perform innovative researches in the area of turbomachines.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction, Classification of turbomachinery	1	To introduce the subject, various turbomachines, classifications and processes
2	Thermodynamics: Adiabatic flow through Nozzles and Diffusers. Work and efficiencies in Turbine and Compressor stages	8	Fundamentals about the thermodynamic analysis of the flow through nozzles and diffusers, and the corresponding analysis

3	Dimensional Analysis: Principle of Similarity, Incompressible and Compressible flow machines, Performance of Turbines, Compressors	6	To introduce the dimensional analysis of various flow machines
4	Axial flow Turbine and compressors: stage velocity diagram, enthalpy entropy diagram, stage losses and efficiency, Performance characteristics	7	An ability to identify, formulate and utilize maximum amount of energy
5	Centrifugal Pumps and Compressors: stage velocity diagram, enthalpy entropy diagram, optimum design at inlet, slip factor, stage losses and efficiency, Performance characteristics	6	The understanding of pumps and compressors, corresponding analysis, and performance evaluation
6	Radial Turbines: stage velocity diagram, enthalpy entropy diagram, stage losses and efficiency, Performance characteristics	5	The understanding of radial turbines, corresponding analysis, and performance evaluation
7	Hydraulic Turbines: Pelton turbine, Kaplan turbine, Francis turbine, effect of size on turbomachine efficiency, cavitation	6	The understanding of hydraulic turbines, corresponding analysis, and performance evaluation

Text Books:

1. S. M. Yahya, Turbines, Compressions & Fans, Tata McGraw-Hill, 2011.

2. S. L. Dixon and C. A. Hall, Fluid Mechanics and Thermodynamics of Turbo machinery, Elsevier, 2014.

References:

3. V. Ganesan, Gas Turbine, Tata McGraw-Hill, 3rd Edition, 2010.

4. M. Dubey, B. V. S. S. S. Prasad and Archana Nema, Turbomachinery, Tata McGraw-Hill, 2018.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED546**	**Conduction and Radiation**	3	0	0	9

Course Objectives

This is introductory course on conduction and radiation heat transfer. This course aims to provide fundamentals concepts and their application in conduction and radiation heat transfer. They will be learning different solution methods to handle the complex problem in conduction and radiation.

Learning Outcomes

Upon successful completion of this course, students will:

1. have a broad understanding of conduction and radiation heat transfer.

2. have analytical and mathematical tools to handle complex heat transfer problem.

3. be able to provide some basic solution to real life conduction and radiation heat transfer problems.

Modules	Topics	Lecture hours	Learning outcomes
1	Review of basic concepts: Introduction to heat transfer, Modes of heat transfer, Differential formulation of the heat conduction equation, Different types of boundary conditions, One dimensional steady state heat conduction with energy generation and variable thermal conductivity. Heat conduction for non isotropic materials, Extended surface: Variable area fins, Introduction to Bessel differential equation and Bessel function	6	Students will review the basic heat transfer. They will learn about steady state conduction and its application. Heat transfer enhancement by extended surface also will be discussed

2	Multi-Dimensional steady-state conduction: Sturm-Liouville Boundary-Value Problem, Orthogonality, separation of variable method, Non-homogeneous Boundary conditions: The method of superposition, 3-D analysis	4	Students will learn to handle multi-dimensional heat conduction and different mathematical approach for its analysis
3	Transient heat conduction: Introduction, Lumped capacity analysis: Improved lumped models, Time dependent Boundary Conditions: Duhamel's superposition integral. Transient heat flow in a semi-infinite solid: The similarity method, The integral method. Time periodic boundary condition conduction problems, Graphical method for conduction problems	6	Transient heat conduction and its analysis will be learned. Learning about time dependent boundary condition and solution.
4	Conduction with phase change: Introduction, The heat equation for moving boundary problems, Non-dimensional form of the governing equations and important governing parameters, Simplified Model: Quasi steady Approximation, Exact solutions: Stefan's solution, Neumann's solution.	7	Specific topics discussing about moving boundary problem and phase change will be analyzed.
5	Perturbation Solution: Introduction, Solution procedure; Perturbation solution examples: transient conduction with surface radiation, conduction with variable thermal conductivity. Introduction to heat conduction in porous media: Simplified heat transfer model	6	Conduction with porous media and perturbation solution will be learned in this module.

6	Review of radiation heat transfer, View factors, The crossed strings method, The inside sphere method, The unit sphere method, Radiant energy transfer through absorbing, emitting and scattering media. Radiative transfer equation (RTE), Beer-Lambert's Law, solution for the straight path, radiative heat flux, Equivalent beam length, Enclosure analysis in the presence of an absorbing or emitting gas.	10	Students will be able to analyze the radiation heat transfer. They will learn different techniques to evaluate view factor. They will also learn about gas radiation.

Text Books:

1. Latif M. Jiji., Heat Conduction, 3rd Edition, Springer, 2009.

2. M. F. Modest, Radiative Heat Transfer, Academic Press, 3rd Edition, 2013.

References:

3. E. R. G. Eckert and Robert M. Drake, Analysis of Heat and Mass Transfer, McGraw-Hill, 1st Edition, 1987.

4. Vedat S. Arpaci, Conduction Heat Transfer, Addison-Wesley series, 1st Revised Edition, 1966.

5. F. Incropera, D. J. Dewitt, T. Bergman and A. Lavine, Fundamentals of heat and mass transfer, Wiley & Sons Inc., 7th Edition, 2011.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED547**	**Convection and Two-Phase Flow**	3	0	0	9

Course Objectives

Advanced treatment of fundamental aspects of convection and two-phase heat transfer. Students pursuing research in the field of convection/two-phase flow can utilize the knowledge for finding new things in this area;

Learning Outcomes

Upon successful completion of this course, students will:

1. have a broad understanding regarding fundamental aspects of convection and two-phase heat transfer.
2. be able to offer ideas about how to analyze various multiphase problems.

Modules	Topics to be Covered	Lecture hours	Learning outcomes
1	Introduction to convection, Derivation of governing mass momentum and energy balance equations, Scale analysis and concept of heat line	3	Students will have concept on convection
2	Boundary layer concept in external flow: Forced convection heat transfer over a flat plate, velocity and thermal boundary layer, Scale analysis, Integral solutions, Similarity solutions	8	Students will have concept on flow over a flat plate

3	Internal forced convection: Hydrodynamic entrance length, Review of duct flow, Thermally and hydraulically developed flow through circular tube: uniform surface heat flux, uniform surface temperature, The Graetz problem	8	Students will have concept on Internal forced convection
4	Laminar boundary layer equations for natural convection,Boussinesq approximation, Scale analysis for high and low Pr number, Integral and similarity solutions, combined natural and forced convection (Mixed Convection)	8	Students will have concept on natural convection
5	Film condensation along a flat plate, Introduction to two phase flow, Flow regimes for single and two component vertical and horizontal flow, Conservation equations based on homogeneous flow, drift flux model, separated flow model (multi-fluid model), Pool boiling curve, film boiling, flow boiling, Experimental methods for boiling and two-phase flow	12	Students will have concept on two phase flow, boiling, and condensation

Text Books:

1. Adrian Bejan, Convective heat transfer, John Wiley & Sons, 4th Edition, 2013.

2. W. M. Kays and M. E. Crawford, Convective heat and mass transfer, McGraw-Hill, 4th Edition, 2017.

References:

3. Louis Bermister, Convective heat transfer, 2nd Edition, 1993.

4. Latif M. Jiji., “Heat Convection”, Springer, 3rd Edition, 2009.

5. Patrick H. Oosthuizen and David Naylor, An introduction convective heat transfer, McGraw-Hill, 2nd Edition, 1990.

6. L. S. Tong, Boiling heat transfer and two phase flow, John Wiley & Sons, 1st Edition, 1965.

7. P. B. Whalley, Boiling, condensation, and gas-liquid flow, Oxford university press, 1st Revised Edition, 1999.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED548**	**Heat Exchanger Design**	3	0	0	9

Course Objectives
1. The objective of the course is to understand the thermal design procedures of different types of Heat Exchangers used is various industrial applications. To get familiarized to different types of standards, charts, templates, property tables, industrial practices etc. required for design of heat exchangers.
Learning Outcomes
1. have a broad understanding of different heat transfer correlations used in various applications. 2. learn the step by step procedure to design various types of heat exchangers. 3. learn to estimate heat transfer rates in heat exchangers under various operating conditions. 4. learn about the material selection and maintenance of heat exchangers.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction to Heat Exchangers, Classification of Heat Exchangers, Direct transfer type, Storage type, Direct contact type, Tubular, Plate and Extended surface H.Es, TEMA Nomenclature of Shell and Tube Heat Exchanger	4	Understanding different types of heat exchangers and their merits, demerits and applications
2	Basic Thermal and Hydraulic Relations in Heat Exchangers Design, Basic Principles of Thermal	6	Understanding the basic methodology for heat exchanger design calculations. To get familiar with

	Design, The effectiveness-NTU Method, Thermal Hydraulic correlations for H.E Design, Shell side flow correlation		various correlations required for design calculations and their applications.
3	The tube side correlations, Thermal Design of Shell and Tube heat exchangers: Kern's Method, Tinker Model, Divided Flow Method, Design considerations	8	Step-by-step design procedure for different approaches for designing shell and tube heat exchanger.
4	Effects of fouling, Design of Condensers and Evaporators, Types and choice of a condenser / evaporators, Heat Transfer coefficient and Pressure drop calculations	8	Learning the effects of fouling in heat exchanger design, Methodology and correlations required for designing condensers and evaporators,
5	Design procedure, Thermal Design of Compact Heat Exchangers, Flow arrangements and Surface Geometries, Heat Transfer and Friction factor data	6	Learning the methodology and correlations required for designing compact heat exchangers.
6	Calculation procedure of compact heat exchanger, Flow induced vibrations in H.E, Tube vibration, Vibration Damage patterns, Regions of tube failures, Heat Exchanger Materials and their manufacturing techniques	7	Learning different mechanisms for flow-induced vibrations and its effects, Learning materials and manufacturing techniques used for heat exchangers.

Text Books:

1. Sadik Kakac and Hongtan Liu, Heat Exchangers – Selection, Rating and Thermal Design, CRC press, 3rd Edition, 2012.

References:

2. A. P. Fraas and M. N. Ozisik, Heat exchanger Design, Wiley New York, 1989.

3. W. M. Kays, Compact Heat Exchanger, McGraw-Hill, New York, 1964.

4. D. Q. Kern, Extended Surface Heat Exchangers, McGraw-Hill, New York, 1st Edition, 1965.

5. G. Walker, Industrial Heat Exchangers-A Basic Guide, McGraw-Hill, New York, 1st Revised Edition, 1983.

6. D. Q. Kern, Process Heat Transfer, McGraw-Hill, New York, 1st Revised Edition, 2007.

7. S. K. Das, Process Heat Transfer, Narosa Publishing House, 2005.

8. Ramesh. K. Shah and Dusan. P. Sekulic, Fundamentals of Heat Exchanger Design, John Wiley and Sons, 2003.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED549**	**Cryogenic Engineering**	3	0	0	9

Course Objectives

To encourage the dissemination of information concerning low temperature processes, techniques, and bringing all those together in all discipline concern with the application of low temperature technologies.

Learning Outcomes

Upon successful completion of this course, students will:

1. be able to know the field of basic thermodynamics, heat transfer, fluids, materials and insulation in cryogenic engineering.

2. be able to know the different cryogenic liquefaction cycles.

Modules	Topics	Lecture hours	Learning outcomes
1	Basic thermodynamics and heat transfer, heat leak and pressure drop in cryogenic transfer lines, properties of cryogenic fluids, material properties at cryogenic temperatures, cryogenic insulations	8	Introduce the students to the field of basic thermodynamics, heat transfer, cryogenic fluids, materials and insulation in cryogenic engineering
2	Liquefaction Cycles: Carnot liquefaction cycle, Joule Thomson Effect, Linde Hampson Cycle, Claudes Cycle, Helium Refrigerated Hydrogen Liquefaction Systems	8	Students will learn different cryogenic liquefaction cycles
3	Cryogenic Refrigerators: J. T. Cryocoolers, Stirling Cycle Refrigerators, G. M. Cryocoolers, Pulse Tube Refrigerators	8	Students will learn different cryogenic refrigerators

4	Cryogenic Instrumentation: strain, displacement, pressure, flow, liquid level, density and temperature.	7	Students will learn basic instruments used in cryogenic engineering
5	Cryogenic Equipment: compressor, pumps, expansion engines, valves, heat exchangers, storage, transfer of liquefied gases.	8	Students will learn basic components used in cryogenic engineering

Text Books:

1. Cryogenic Engineering, Klaus D. Timmerhaus, Richard Reed, Springer, New York, 2010.

2. Fundamentals of Cryogenic Engineering, Mamata Mukhopadhyay, PHI Learning Pvt. Ltd., 2010.

References:

3. Cryogenic Systems, Randall F. Barron, McGraw-Hill, 1985.

4. Cryogenic Heat Transfer, Gregory Nellis and Randall F. Barron, CRC Press, 1999.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED550**	**Combustion and Emission in I.C. Engines**	3	0	0	9

Course Objectives

1. To broaden the perspectives of Combustion and thereby Emission of IC Engines that the students were introduced to in their undergraduate course of Automobile Engineering.

2. To understand the process of combustion of engines and how the process is different from normal daily life combustion process.

3. To introduce advanced details that will increase the curiosity, and therefore improve the ability to explain the combustion process through physics supported by mathematical analysis.

Learning Outcomes

1. Students will understand the combustion thermo-chemistry, mass transfer and flames, which will be needed for their master's research.

2. Strong foundation of the combustion processes and flame physics.

3. Understanding of the close coupling between combustion and emission process of IC Engines.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction, Engine classifications - Engine components - S.I. Engine operation – C.I. Engine operation – Relative merits and demerits	3	Recapitulation of the IC Engine processes, components, operations, and emissions, which have been already taught in the undergraduate course. The module is to guide the students towards the engine combustion process
2	Engine performance parameters	5	This important module will enable the students to understand the engine performance parameters and the evaluation of those parameters

3	Fuels, Desirable properties – SI engine fuels – CI engine fuels - Alternative fuels – Alcohols - CNG – LPG – Hydrogen - Biodiesels – Biogas - Dual fuel operation	4	The students will be acquainted with various fuels, conventional and non-conventional, which are used in engines
4	Combustion in SI Engines, Introduction – Thermodynamic Analysis - Stages of combustion in SI Engine - Flame front propagation– Factors influencing flame speed - Rate of pressure rise – Analysis of cylinder pressure data – Heat release analysis - Cyclic variations in combustion, partial burning and misfire – Abnormal combustion and knocking – Effects of detonation - Effect of engine variables on detonation – SI Engine combustion chamber design principles – Types of combustion chambers	8	The module introduces the students to the combustion process that occurs inside various SI engines and how the process governs the generations of various emissions
5	Combustion in CI Engines: Introduction – Stages of combustion in CI Engine – Ignition delay – Factors effecting ignition delay – Knocking in CI Engine – Factors affecting knocking	7	The module introduces the students to the combustion process that occurs inside various CI engines and how the process governs the generations of various emissions
6	Types of Diesel Combustion systems – Direct injection systems - Indirect injection systems, comparison of combustion Systems - Combustion in direct injection multi spray – Analysis of cylinder pressure data - Heat release analysis	6	This module focuses on various injection systems that exists in CI engines and how the combustion process and the heat release is related for those systems
7	Emission, Pollution Norms- Types of pollutants, Measurement of Emissions, Exhaust gas treatment	6	The students will be accustomed with the emission norms, and how to measure and treat the emissions in real life

Text Books:

1. John B. Heywood, Internal Combustion Engine Fundamentals, McGraw-Hill Education; 1st Edition, 2017.

2. Stephen R. Turns, An Introduction to Combustion: Concepts and Applications, McGraw-Hill Education; 3rd Edition, 2017.

References:

3. E. F. Obert, Internal Combustion Engine and Air Pollution, Harper and Row Publishers, 1st Edition, 1973.

4. V. L. Maleeve, Internal Combustion Engines, McGraw-Hill Book Company, 1st Edition, 1945.

5. Colin R. Ferguson and Allan T. Kirkpatrick, Internal Combustion Engines, Wiley publishers, 1st Edition, 2000.

6. V. Ganesan, Internal Combustion Engines, Tata McGraw-Hill, 4th Edition, 2013.

7. H. N. Gupta, Fundamentals of Internal Combustion Engines, PHI, New Delhi, 2nd Edition, 2015.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	**MEO579**	**Computational Fluid Dynamics**	3	0	0	9

Course Objectives
1. The prime objective of this course is to provide the students with in depth understanding of the computational approach for modeling and solving fluid dynamics as well as heat transfer problems. 2. To enable the students to mathematically represent a physical phenomenon, so that they can generate a mathematical model and finally, a numerical statement of a given problem and solve the problem via implementation of the theoretical knowledge gained. 3. To make the students initially believe and then understand that many of the results in heat transfer/fluid flow that they have studied in undergraduate/post-graduate courses can be generated accurately by themselves using CFD.
Learning Outcomes
1. The students will be familiar to a powerful tool for solving flow and heat transfer problems. This experience will enable them to numerically model a thermo-fluids problem using FDM and FVM. 2. The students will have the feel of the essential role the matrix algebra plays in approximate computations of ODEs and PDEs. 3. The students will be more inclined towards computer programming which will turn out to be very helpful in their Masters research and thereafter.

Modules	Topics	Lecture hours	Learning outcomes
1	Review of governing equations for conservation of mass, momentum and energy in primitive variable form	3	After this revision module, the students will be able to derive the conservation equations using Reynolds transport theorem and will also be able to interpret each equation
2	Mathematical behaviour of the conservation equations, equilibrium and marching problems	3	This important module will enable the students to distinguish given equations based on their characteristics (mathematical nature) and also to choose later, the appropriate differencing schemes as applicable
3	The finite difference method (FDM) and the variational methods, discretization, comparison of finite difference method, finite volume method (FVM) and finite element method (FEM)	2	The students will be acquainted with the brief history of development of the three basic discretization techniques as well as foundation of discretization
4	Review of Taylor's series, implicit, explicit and semi-implicit schemes, alternate direction implicit method	6	This module deals with the foundation of FDM; the students will be able to logically approximate a derivative and a differential equation
5	Convergence, stability analysis of a numerical scheme	4	This module will provide the concept of numerical error and guidelines for using or not using a differencing scheme while solving a CFD problem
6	Solution of linear matrix equation system and programming	2	This module will familiarize the students with the role of linear algebra in solving fluid dynamics problems
7	Application of FDM in one- and two dimensional steady and unsteady heat conduction and computer programming, artificial viscosity, upwinding	5	Practical implementation of all the topics covered up to module VI, introduction to numerical diffusion and CFD in fluid flow, students will be able to differentiate between CFD in heat conduction and CFD in fluid dynamics

8	Stream function-vorticity formulation	3	The students will learn the alternate flow equations as well as their solution methods used in early days of numerical treatment of flow problems
9	The finite volume method in orthogonal and non-orthogonal meshes, Green-Gauss theorem, application of FVM for heat conduction and convection-diffusion problem	7	The students will be able to discretize a given equation via direct integration on orthogonal and non-orthogonal meshes. This module will make the limitations of FDM more obvious to the students
10	Implementation of SIMPLE algorithm in two dimensions, Introduction to commercial package ANSYS-FLUENT	4	The students will have the flavour of a segregated fluid flow solver. In this context, they will learn the difficulties posed by the nonlinear convective terms and coupling between pressure and velocity. Thus, they can appreciate the depth and involvement in numerical treatment of a flow problem compared to a heat conduction problem

Text Books:

1. John D. Anderson, Computational Fluid Dynamics The basics with applications, McGraw-Hill Education, 1st Edition, 2017.

References:

2. Richard H. Pletcher, John C. Tannehill and Dale A. Anderson, Computational Fluid Mechanics and Heat Transfer, CRC Press, 3rd Edition, 2012.

3. Joel H. Ferziger and M. Peric, Computational Methods for Fluid Dynamics, Springer, 3rd Edition, 2002.

4. Clive A. J. Fletcher, Computational Techniques for Fluid Dynamics, Springer, 1st Edition, 1988.

5. T. J. Chung, Computational Fluid Dynamics, Cambridge University Press, 2nd Edition, 2010.

5. K. Muralidhar and T. R. Sundararajan, Computational Fluid Flow and Heat Transfer, Narosa Publishing House, 2nd Revised Edition, 2003.

6. S. V. Patankar, Numerical Heat Transfer and Fluid Flow, CRC Press, 1st Edition, 1980.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	**MEO580**	**Measurements in Thermal Engineering**	3	0	0	9

Course Objectives
Aims to provide the fundamental knowledge of experimental methods in the field of fluid mechanics and heat transfer which will help the students while performing real time experiments and also to understand their applications in real life problems.
Learning Outcomes
Upon successful completion of this course, students will be able: 1. to understand the various measurement techniques and errors associated with measurement analysis. 2. to determine uncertainty in the measurement analysis. 3. to understand about the different measuring devices like Hot wire anemometer, Laser Doppler velocity meter, Capillary method, Saybolt viscometer, Manometer, Pirani gauge, Ionization gauge, Dynamic response of a U-tube manometer, Resistance Thermometer, Pyrometry, etc. 4. to apply the knowledge of fixing permissible error in a measuring device and the importance of considering error while calculating different physical parameters.

Modules	Topics	Lecture hours	Learning outcomes
1	Basic concepts of measurements, Different types of errors in measurements, Statistics in Measurements, Uncertainty in measurements, Linear regression, Parity plot	8	To understand the different types of errors associated with measurement analysis and the determination of uncertainty in measurements

2	Temperature measurements: Thermometer, thermocouples, Temperature measurement in the solid, Measurement of Transient temperature, Resistance Thermometer, Pyrometry	8	To understand the theory and working principles of different instruments used for temperature measurements
3	Measurements of Heat Flux, Interferometry, Differential Interferometer	3	To understand the theory and working principles of different instruments used for heat flux measurements
4	Thermal conductivity measurement: Guarded hot plate apparatus, heat flux meter .	3	To understand the theory and working principles of different instruments used for the thermal conductivity measurements
5	Pressure measurements: Manometer, Vacuum measurements, Pirani / Ionization gauges, Dynamic response of a U-tube manometer	7	To understand the theory and working principles of different apparatus used for the pressure measurements
6	Flow and velocity measurements: Different methods of incompressible and compressible flow measurements, Pitot static tube, Hot wire anemometer, Ultrasonic method, Doppler effect, Vortex Shedding Flow meter, Laser Doppler velocity meter	7	To understand the theory and working principles of different instruments used for the measurements of flow velocity
7	Viscosity Measurement: Capillary method, Torque method, Saybolt viscometer	3	To understand the theory and working principles of different instruments used for viscosity measurements

Text Books:

1. J. P. Holman, Experimental Methods for Engineers, McGraw-Hill Science Engineering; 8th Edition, 2011.

2. S. P. Venkateshan, Mechanical Measurements, John Wiley & Sons and Ane Books Pvt. Ltd., 2nd Edition, 2015.

References:

3. S. M. Yahaya, Compressible Flow, New Age International (p) Ltd., 5th Edition, 2016.

4. E. O. Doebelin, Measurement systems, Application and Design, Tata McGraw-Hill, 5th Edition, 2007.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	**MEO581**	**Fundamentals of Combustion**	3	0	0	9
Course Objectives						
1. The course is to familiarize the students with the basics of combustion process, the equations involved, flame and its propagation, spray combustion, etc. 2. The subject is important for various automobile and oil industries, so fundamental knowledge will help in getting jobs in these industries.						
Learning Outcomes						
Upon successful completion of this course, students will be able: 1. to understand basics of combustion process, the equations involved, Droplet evaporation, Atomization, Spray Combustion. 2. to understand governing equations for a reacting flow, general characteristics of combustion, volumetric combustion. 3. to get jobs in automobile/oil industries.						

Modules	Topics	Lecture hours	Learning outcomes
1	Fuels and their properties, Review of basic thermodynamics and gaseous mixtures	3	To understand the different types of fuels and their properties, review of basic thermodynamics
2	Combustion Thermodynamics; Stoichiometry, First and second Laws of thermodynamics applied to combustion; Heat, temperature and composition products in equilibrium	5	To understand the first and second laws of thermodynamics applied to combustion
3	Mass transfer basics	6	To understand the basics of mass transfer

4	Fundamentals of combustion kinetics	4	To understand the basics of combustion kinetics
5	Governing equations for a reacting flow, General characteristics of combustion, volumetric combustion, explosion and detonation	6	To understand the basic equations for reacting flows, general characteristics of combustion, explosion / detonation
6	Laminar flame propagation; deflagration, premixed flame burners, theories, Flammability limits, partial premixing and quenching of laminar flames, Ignition, Flame stabilization, Gas jets and combustion of gaseous fuel jets, Turbulent premixed and non-premixed flames	8	To understand the theory of laminar flames, flame propagation, Flame stabilization, Turbulent premixed and non-premixed flames
7	Droplet evaporation and combustion, Atomization, Spray Combustion, Solid fuel combustion	7	To understand the theory of droplet evaporation, spray combustion

Text books:

1. Stephen R. Turns, An Introduction to Combustion: Concepts and Applications, McGraw-Hill Education; 3rd Edition, 2017.

References:

2. Kenneth Kuo, Principles of Combustion, John Wiley, 2nd Edition, 2005.

3. Irvin Glassman, Combustion, Academic Press, 5th Edition, 2014.

4. F. A. Williams, Combustion Theory, ABP, 2nd Edition, 199

5. H. S. Mukunda, Understanding Combustion, Macmillan India.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	**MED573**	**Advanced Optimization Techniques**	3	0	0	9

Course Objectives
1. To understand theory of different optimization methods to solve various types of engineering problems. 2. To understand physical engineering problem and to construct mathematical formulation towards solving it by selecting proper optimization techniques. 3. To understand both computer programming and heuristic approaches to solve optimization problems.
Learning Outcomes
Upon successful completion of this course, students will: 1. have a broad understanding on formulation of engineering optimization problem, especially for mechanical engineering. 2. have an understanding about solving the real life/ industrial /engineering/ environmental/ social problems using conventional optimization methods, that helps to take decision. 3. be able to write MATLAB code for single and multivariable engineering problems. 4. be able to understand and write MATLAB code for nontraditional optimization technique like GA, ANN, fuzzy logic to solve different engineering problems with single objective function and multi-objective function.

Modules	Topics	Lecture hours	Learning outcomes
1	Basic Concepts: optimization problem formulation	2	Understanding the types and basic concept of engineering optimization problem formulation.

			Especially real life / industrial / engineering / environmental / social problems
2	Single variable optimization algorithms: Exhaustive search method, bounding phase method, Interval halving method, Fibonacci method, golden search method, Newton Rapshon method, bisection method, secant method. Formulation of engineering problem with single variable. Computer programming to solve the single variable problem	6	This unit discuss about different types of classical single variable optimization algorithms. Student will learn to write MATLAB code for these algorithms also
3	Multivariable optimization algorithms: Unidirectional search, direct search methods: simplex search, gradient based methods: Cauchy's Steepest Descent method Formulation of engineering problem with multiple variable. Computer programming to solve Multivariable optimization algorithm	8	This unit discusses about different types of classical multivariable unconstrained optimization algorithms. Student will learn to write MATLAB code for these algorithms also
4	Constrained optimization algorithms: Linear programming, nonlinear programming penalty function method, method of multipliers, sensitivity analysis, direct search for constrained minimization. Formulation of engineering problem with constrained multiple variable. Related computer Programming.	6	Students will learn constrained optimization algorithms and their computer programming
5	Nontraditional optimization: Introduction to Genetic algorithm (GA), Artificial Neural Network (ANN), fuzzy logic etc with single objective function. Computer programming, other evolutionary algorithms. Formulation of engineering problem and solve with Nontraditional optimization.	9	This unit demonstrates basics of Nontraditional optimization techniques. Use of Nontraditional optimization like GA, ANN, fuzzy logic with single objective function to solve different engineering problem

6	Multi-Objective Optimization: Introduction to linear and nonlinear multi-objective problems, Use of Evolutionary Computations to solve multi objective optimization with computer programming in MATLAB	8	This unit demonstrates Nontraditional optimization techniques to solve different engineering problem with multi objective function

Text Books:

1. Deb, K., Optimization for engineering design: algorithms and examples, Prentice Hall of India, New Delhi, 2nd Edition, 2012,

References:

2. Deb, K., Multiobjective optimization using evolutionary algorithm. Wiley. 1st Edition, 2001.

3. Rao, S. S., Engineering Optimization: Theory and Practice, Wiley, 3rd Edition, 2014.

4. Ravindran, A., Ragsdell, K. M. and Reklaitis, G. V., Engineering Optimization: Methods and applications, Wiley, 2nd Edition, 2013.

5. Rardin, Ronald L., Optimization in operations research, Prentice Hall.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	**MEO582**	**Flow and Transport Phenomena Through Piping System**	3	0	0	9

Course Objectives
1. To study transport of fluids in pipe. 2. To study about the components of piping system. 3. To study different application of piping system in agriculture, drainage, drinking and other industry applications.
Learning Outcomes
Upon successful completion of this course, students will: 1. have a broad understanding about fluids properties flowing through pipeline and transport theory. 2. have an understanding about the application of piping system in different field. 3. be able to use soft techniques to solve fluid distribution problem through pipe network. 4. be able to understand reasons behind erosion and corrosion occurred in pipeline and their remedy

Modules	Topics	Lecture hours	Learning outcomes
1	Basic Concepts: Conservation of mass, energy, momentum, second law of thermodynamics, unit and dimensions, fluid properties in perspective.	6	Understanding basic concept of fluid properties and laws of thermodynamics.

2	Introduction to Transport phenomenon, Momentum transport: Viscosity and mechanisms of Momentum transport, velocity distribution in laminar and turbulent flow, Energy Transport, Mass Transport.	9	Understanding the transport phenomenon through pipe.
3	Transport of fluids in piping system: pipe flow, noncircular conduits, economic pipe diameter, various fittings, Non-Newtonian fluids, pumps and compressors, pipe network problems. Solve pipe network problem using BENTLEY HAMMER software.	9	Understanding piping system components and their design aspects.
4	Applications: Pipelines for water conveyance and drainage: Materials, Specifications and industry standards, Available sizes, system of units, corrosion, Fluid and Gas in Pipelines: Governing Factors, Slurry Transport: Rheometry and Rheological Models, Turbulent Flow of Non-Newtonians, Effects of Solids Concentration, Heat pipes: heat transfer and fluid flow theory.	9	Understanding different application of piping system in agriculture/drainage/industry, etc, and the flow characteristics.
5	Thermodynamics of corrosion. Fundamentals and application of corrosion theories, interaction of corrosion with erosion. Corrosion Control- Design improvement.	6	Understanding different problems arises due to flow in pipeline and the remedies.

Text Books:

1. Ron Darbyand, Raj P. Chhabra, Chemical Engineering Fluid Mechanics, CRC Press; 3rd Edition, 2016.

References:

2. Bird, R. B., Stewart, W. E., Lightfoot, E. N. and Klingenberg, D. J., Introductory Transport Phenomena, Wiley, 2015.

3. Christie J. Geankoplis, Transport process and unit operations, Prentice-Hall International, University of Minnesota, 3rd Edition, 1993.

4. Bird, Stewart, Lightfoot, Transport Phenomena, Wiley, 2nd Edition, 2002.

5. W. M. Deen, Analysis of Transport Phenomena, Oxford University Press, 2nd Edition, 2012.

6. E. L. Cussler, Diffusion: Mass Transfer in Fluid Systems, 3rd Edition, 2009.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	**MEO583**	**Design of Thermal systems**	3	0	0	9

Course Objectives

1. The objective of the course is to equip the students with the techniques to design, simulate and optimize different thermal systems.

2. It enables the students to optimize the design of the thermal systems.

Learning Outcomes

Upon successful completion of this course, students will:

1. be able to utilize his knowledge of thermodynamics, heat transfer, and fluid mechanics in design of integrated thermal system.

2. be able to perform a thermal system simulation and solve for a workable solution using the method of successive substitution.

3. have a broad understanding formulation of engineering optimization problem, especially for thermal systems.

4. evaluate thermal systems based on life-cycle economics.

Modules	Topics	Lecture hours	Learning outcomes
1	Thermal system design, Design objectives, Principles of thermal design	6	This chapter will make the student understand the requirement, steps involved and to formulate a design problem. This chapter will also recapitulate the basic principles of heat transfer, thermodynamics and fluid flow which are widely used in this course.

2	Regression and curve fitting, System simulation (Successive substitution-Newton Raphson method)	8	To learn both linear and non-linear regression analysis and to develop different correlations based on the experimental results and to use the same for complete system simulation of complex thermal systems using various numerical root finding techniques.
3	Modelling of systems. Methods of optimization, Lagrange multipliers, Dynamic programming, Geometric programming, Linear programming	12	This module discusses about the different optimization techniques and makes the student well equipped to generate an objective function and the appropriate constraints for a complete thermal system design problem.
4	Economic consideration	6	This module will to make the student conversant with economic analysis of any engineering system with a view to arrive at a cost effective system.
5	Case studies, Examples applied to heat transfer problems and energy systems such as gas and steam power plants, refrigeration systems, heat pumps and so on	7	This module will help students in applying their understanding on design and optimization of thermal system to various complex systems of process industry, tri-generation units etc.

Text Books:

1. W. F. Stoecker, Design of thermal systems, Tata McGraw-Hill, 3rd Edition, 2011.

References:

2. Yogesh Jaluria, Design and Optimizations of Thermal systems 2nd Edition, CRC Press.

3. C. Balaji, Essentials of Thermal System Design and Optimization Ane Books Pvt. Ltd, 2nd Edition, 2007.

4. Adrian Bejan, George Tsatsaronis and Michael Moran, Thermal Design and Optimization, John Wiley and Sons, 1st Edition, 1995.

5. L. C. Burmeister, Elements of thermal fluid system design, Prentice Hall, 1st Edition, 1997.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	**MEO584**	**Waste Heat Utilization**	3	0	0	9

Course Objectives
1. Studies from various industries suggest that 20 to 50% of industrial energy input is lost as waste heat, which may be in the form of hot exhaust gases, heat lost from hot equipment and surfaces, etc. 2. Designed to make the students conversant with various methods of waste heat recovery that has been employed by the industry.
Learning Outcomes
Upon successful completion of this course, students will: 1. To be able to design power plant based on waste heat recovery. 2. To be able to design refrigeration and air conditioning system using solar energy. 3. To be able to design different thermal storage systems.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction to different sources of waste heat, industrial waste heat Importance of Waste Heat Recovery, Review of Thermodynamics – Introduction to First and Second Laws	4	Understanding about waste heat and industrial waste heat

2	Power Plant Cycles - Modification of Rankine cycle, Energy Cascading, Combined Cycle, Combined Gas Turbine-Steam Turbine Power Plant, Heat Recovery Steam Generators	8	For understanding further topics, students will learn different thermodynamic cycles
3	Direct conversion technologies – MHD-Steam power, Thermoelectric Generators, Thermionic conversion, solar energy conversion, Thermo-PV	8	Students will learn different types of energy conversion systems
4	Energy Storage Techniques – Pumped hydro, Compressed Air, Flywheel, Superconducting Magnetic storage Thermal storage (Sensible & Latent), Battery, Chemical Energy Storage, Fuel cells	8	Students will learn different storage systems
5	Utilization of waste heat in organic Rankine cycle engines, in refrigeration and air-conditioning systems	5	Understanding about utilization of waste heat in refrigeration and air-conditioning systems
6	Waste Heat recovery systems: Heat Exchangers, Waste heat boilers, Heat Pipes, Fluidized bed waste heat recovery systems	6	Different types of waste heat recovery systems will be discussed

Text books:

1. P. K. Nag, Power Plant Engineering, Tata McGraw-Hill, 4th Edition, 2014.

2. S. Sengupta (Editor) and S. S. Lee (Editor)**:** Waste Heat: Utilization and Management, Springer, 1st Edition, 1983.

References:

3. Robert Goldstick and Albert Thumann, The waste heat recovery handbook, Fairmont Press, 1983.

4. R. Yadav, Steam & Gas Turbines and Power Plant Engineering, Central Publishing House, 7th Edition, 2000.

5. Goldstick, R. J. and Thumann, A: Principles of waste heat recovery, United States: N. p., 1985. Web.

COURSE WORK IN MANUFACTURING ENGINEERING

MONSOON SEMESTER **Five Compulsory Courses**

Course No.	**Course Name**	Semester	**L**	**T**	**P**	**CH**
MEC502	Numerical Methods	1st	3	0	0	9
MEC514	Advances in Machining	1st	3	0	0	9
MEC516	Unconventional Manufacturing Processes	1st	3	0	0	9
MEC591	Research Methodology and Statistics	1st	3	0	0	9
HSI500	Research and Technical Communication	1st	3	0	0	9

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEC 514	Advances in Machining	3	0	0	9

Course Objective
The objectives of this course is to train the students : to select suitable machines and cutting tools for different operations on a work material; to address the issues related to high cutting temperature, low tool life, effective use of cutting fluids; to understand the mechanics of metal cutting in different operations, hybrid machining process and different research areas.

Learning Outcomes

Upon successful completion of this course, students will:

- Understand the different cutting tool geometrical parameters and methods for their quantification
- Understand the principle of metal cutting process.
- Able to measure and estimate cutting force and temperature in different metal cutting operations
- Get idea of about the difficulties in metal cutting operations and the possible approaches to overcome them.

Module	Topics	Lecture Hours	Learning Outcome
1	Need and Classifications of Machining Processes; Cutting Tool Geometry in different systems: tool in hand, ASA, ORS, NRS etc. and their conversion; Cutting tool materials and selection; Drilling, milling tool geometry.	8	Students will learn the selection of proper cutting tool for a particular work material. Tool designation in different systems of reference of references and conversation of angles.

2	Mechanics of metal cutting, Orthogonal and Oblique cutting, Mechanism of chip formation and Types of chips: Turning, Drilling and Milling. Metal Cutting forces, cutting Temperature and their measurement methods, Tool Life.	12	Students will understand mechanics of chip formation in different machining process. Measurement methods of cutting forces involved. Determination of tool life, mathematical relations in machining process and their applications.
3	Advanced machining processes: high speed, cryogenic and dry machining, hard cutting, ultrasonic assisted machining.	4	Students will be able to understand how hybridization of machining process is beneficial in material removal process, machining techniques for very hard and tough materials. Effects of with and without coolant in machining.
4	Grinding processes: Grinding Wheel and types; Mechanics of Grinding, spark in and spark out, grinding stiffness, residue in grinding, grinding specific energy, and Chip Formation; Grinding Forces and Power; Grinding Temperature; Cooling and lubrication: principle and types, cutting fluids and method of application: Flood flowing, MQL, nano lubricants etc.	15	This module will teach the requirements of different grinding operations, parameters, energy consumption, forces and power requirements.

Text books:

1. Machining and Machine Tools, A.B. Chattopadhyay, Willey Publishers, 2011

References books:

1. Theory of Metal Cutting, A. Bhattacharya.
2. Materials and Processes in Manufacturing, Degarmo, J. T. Black, PHI Pvt Ltd.
3. Manufacturing Processes for Engineering Materials, Kalpakjian and Schmid, Prentice Hall.Fundamentals of Metal Machining and Machine Tools, Winston A. Knight, Geoffrey Boothroyd, CRC Press
4. Manufacturing Science : Ghosh and Mallick, East-West Press Private Limited
5. Machining and Metal Working Handbook, Ronal A Walsh and Denis Cormier McGraw Hill Publication.Hand book of Manufacturing Engg and Technology, Edited by Andrew YC Nee, Springer, 2014

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEC 516	Unconventional Manufacturing Processes	3	0	0	9

Course Objective
To provide detailed understanding of advanced manufacturing processes. The prospect of future research will also discuss in the course which will encourage the PG students to carryout research in the advance area,
Learning Outcomes
Upon successful completion of this course, students will: • Broad understanding of machining using different energy sources. • Students will be able to think about the possibility of combining different process to develop more efficient machining process • It will help the students to select the best process among various alternative.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction and classification, Theory of machining by Abrasive Jet, Abrasive water Jet, Abrasive flow; Ultrasonic machining.	8	Understanding of mechanical based unconventional processes (UMP). It will develop the ability of select the process for particular application.
2	Electrochemical Machining and grinding, polishing, sharpening, honing and turning. Chemical Machining. Electrochemical Discharge machining and Grinding; Electro-stream and Shaped Tube Electrolytic Machining.	13	Understanding of electrical and chemical based unconventional processes (UMP). The students will learn the principle of hybrid process and their applications.
3	Thermal energy methods of material processing (machining/welding/heat treatment) by Electro-	12	Understanding of thermal based unconventional processes (UMP).

	discharge, Laser and Electron beam, Plasma arc and Ion beam.		The students will learn the importance of high pulse energy source.
4	Unconventional metal forming processes: principle, working and applications, High Energy Rate Forming and Electroforming, Physical Vapour and Chemical Vapour Deposition and Plasma Spraying.	6	The students will understand the use of controlled explosive and spark energy in deformation process. The students will also learn about thin coating techniques.

Text books:

1. Fundamentals of Machining Processes (Conventional and Nonconventional Processes), Hassan Abdel-Gawad El-Hofy, CRC press, 3rd Edition, 2018

Reference books:

1. Non-traditional manufacturing processes , Gary F. Benedict, CRC press, 2015
2. Fundamentals of modern manufacturing processes, M. P. Groover.
3. Unconventional Machining, P K Mishra
4. Unconventional Machining, V K Jain
5. Unconventional Machining, Pandey and Shah

WINTER SEMESTER

Four elective courses from Winter Semester

	PG Level Courses	Semester				
Course no	Course Name		**L**	**T**	**P**	**CH**
MED553	Laser Processing of Materials	2nd	3	0	0	9
MED554	Surface Engineering	2nd	3	0	0	9
MED555	Computer Aided Manufacturing and Robotics	2nd	3	0	0	9
MED556	Design of Tools, Jigs and fixture	2nd	3	0	0	9
MED529	Composite materials	2nd	3	0	0	9
MED557	Micro-Electro-Mechanical-System (MEMS)	2nd	3	0	0	9
MED558	Micro-manufacturing	2nd	3	0	0	9
MED559	Micro and Precision Engineering	2nd	3	0	0	9
MEO585	Quality Engineering and Management	2nd	3	0	0	9
MEO586	Additive manufacturing	2nd	3	0	0	9
MEO587	Advanced Manufacturing systems	4th	3	0	0	9
MED573	Advanced Optimization Technique	4th	3	0	0	9

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED553	Laser Processing of Materials	3	0	0	9

Course Objective
Students will learn about the applications of various types' lasers in industry/research. Laser interaction with the solids. Lasers operations in material removal, joining, forming and surface modification processes.
Learning Outcomes
Upon successful completion of this course, students will able to: • Understand the uses of laser for processing of materials • Use laser for different applications like cutting, drilling, marking etc. • Understand the principle of laser based Additive Manufacturing Process

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction to industrial lasers: He-Ne, CO2, Excimer, Nd:YAG, Diode, Fiber and Ultra-short pulse lasers and their output beam characteristics; laser beam delivery systems. Laser interaction with the materials.	6	Student will be able to understand different lasers and their applications, laser parameters and their control for engineering applications, Safety precautions.
2	Industrial & scientific applications of laser; Laser cutting, drilling, welding, marking and their process characteristics.	10	After completion of this module, the learner will understand the process physics of laser cutting, drilling, marking etc.
3	Laser surface modifications: Heat treatment, surface remelting, surface alloying and cladding, surface texturing, LCVD and LPVD.	8	This module emphasizes the application of lasers for various surface modification processes.

4	Ultra-short laser processes; pulse interaction, metallurgical considerations and micro fabrication.	6	The student will understand the laser based cold cutting process.
5	Laser additive manufacturing. Laser metal forming: Mechanisms involved including temperature gradient, buckling, upsetting. Laser peening: Laser Shock Processing.	9	This module will enlighten the applications lasers in additive manufacturing, sheet metal forming.

Text books:

1. Steen, William M., Jyotirmoy Mazumder. Laser material processing. Springer science & business media, 2010.

References books:

2. Ion, John. Laser processing of engineering materials: principles, procedure and industrial application. Elsevier, 2005.
3. Duley, Walter W. Laser processing and analysis of materials. Springer Science & Business Media, 2012.
4. Chryssolouris, George. Laser machining: theory and practice. Springer Science & Business Media, 2013.
5. Schaeffer, Ronald. Fundamentals of laser micromachining. CRC press, 2016.

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED554	Surface Engineering	3	0	0	9

Course Objective
To have systematic and comprehensive understanding on various aspects related with surface engineering of metallic components.
Learning Outcomes
Upon successful completion of this course, students will able to: • Identify and design the suitable surface modification methods for different applications • Characterise the metallurgical, mechanical and tribological properties of engineered surfaces.

Module	Topics	Lecture Hours	Learning Outcome
1	Fundamentals of surface engineering: definition, scope, classification, and general principles, surface dependent properties and failures, Surface and surface energy: Structure and types of interfaces.	4	Understanding of surface properties and their influences on the performance of a component.
2	Conventional surface engineering practice: Surface engineering by material removal: like etching, grinding, polishing, etc. Surface engineering by material addition: like hot dipping, Electro-plating, carburizing, Cyaniding, etc.	6	Understanding on the fundamental of basic surface modification techniques.
3	Surface engineering by energy beams: Laser assisted microstructural modification like surface melting, hardening, shocking etc., Laser assisted compositional modification like surface alloying, surface cladding, composite surfacing etc. Surface engineering by spray techniques like Flame spray, cold spray etc.,	12	Understanding of thick layer coating technology and their applications.
4	Ion beam assisted microstructure and compositional modification, Sputter deposition of thin films & coatings, PVD coating processes, Chemical vapour deposition and PECVD.	10	Understanding of thin layer coating technology and their applications.
5	Characterization of coatings and surfaces: Measurement of coatings thickness, porosity & adhesion of surface coatings, Measurement of residual stress & stability, Surface microscopy, topography and Spectroscopic analysis of modified surfaces.	7	Understanding about methods of characterization needed for evaluating the metallurgical, mechanical and tribological properties of engineered surfaces.

Text books:

3. Introduction to Surface Engineering by P. A. Dearnley, Cambridge University Press, 2017
4. Laser surface modification of alloys for corrosion and wear resistance by Chi Tat Kwok, Woodhead Publishing Limited, 2012

Reference books:

3. Surface Engineering for Corrosion and Wear Resistance by J.R. Davis, ASM international , 2001
4. ASM Hand book – Surface Engineering, ASM International, vol. 5, 9th edition, 1994

Surface Engineering for Wear Resistances by K.G. Budinski. Prentice Hall Publisher, 1988

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED555	Computer Aided Manufacturing and Robotics	3	0	0	9

Course Objective

To provide detailed understanding of advances in manufacturing particularly in computer numerical control and robotics.

Learning Outcomes

Upon successful completion of this course, students will:

- Broad understanding of Computer Numerical Control machines and working of its components.
- The students will able to learn the CNC programming for the machining given engineering component design.
- Students will also learn about the functioning of robots used in manufacturing environment.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction, Evolution, Benefits of CAM, Role of management in CAM.	03	Understanding of broad aspect of advances in manufacturing and its impact on productivity.
2	NC/CNC Machine Tools: NC and CNC Technology: Principles, Classification, Specifications and components, Construction Details: interpolators for machining, drives, feedback devices, tooling, adaptive control systems; CNC Applications.	12	Understanding of difference between different CNC technology, its basic components, and different sensors used in CNC machines. The students will learn the principle of interpolators, derives and sensors used in CNC.

3	CNC Programming: Types, Manual Part Programming, canned Cycles and loops, Automated Part programming. Simulation of machining process.	12	Understanding of thermal based unconventional processes (UMP). The students will learn the importance of high pulse energy source.
4	Robotics: Introduction, classification and applications, basic concepts of robot, manipulators, control and drives, robot programming, feedback devices. Technologies, Industrial robot, Kinematics of robots.	12	The students will learn the basic function of robotics and its application.

Text books:

1. Computer control of Manufacturing system, Yoram koren, McGraw Hill Publication, Reprint 2005

Reference books:

2. Industrial Robotics Technology, Programming, and Application, M. P. Groover et al, Tata McGraw-Hill Publication. 2018

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED556	Design of Tools, Jigs and Fixtures	3	0	0	9

Course Objective
Students will learn about tooling and job holding requirements during different manufacturing operations. Another objective is to understand the design and selection criteria for jigs and fixtures for bulk and sheet metal processes.
Learning Outcomes
Upon successful completion of this course, students will: • Be able to acquire fundamental knowledge on tool design and clamping methods in different industrial environmental applications.

- Formulate mathematical and scientific methods associated with design of a mechanical system.
- Finally, it will be helpful in customizing design and development of a new system as per the requirement.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction: Tool design methods; tool making practices: hand finishing and polishing, screws and dowels, hole location and jig boring practices. Tooling materials tool steel, cast iron, non-metallic tooling material, heat treatment and factor affecting the heat treatment.	10	Understanding the different tool design methods and factors affecting the design criteria.
2	Design of cutting tools: Basic Requirement of The Cutting Tools, Metal Cutting Tools and classification. Gauges and gauge design: fixed gauges, gauge tolerance, selection of materials for gauge.	9	Characterizing the cutting tools and its specification criteria in different applications
3	Locating and clamping methods, Classification of jigs, design of drill jigs and milling fixtures, other fixtures: Turning, Grinding, Broaching, Welding and Modular Fixtures,	10	Application of jigs and fixtures in conventional manufacturing processes,
4	Design of sheet metal blanking and piercing dies, sheet metal bending, forming and drawing dies, tool design for numerical control machine tools.	10	Design and application of dies in sheet metal operations

Text books:

1. Donaldson C, LeCain GH, Goold VC, Ghose J. Tool design. Tata McGraw-Hill Education; 2012

References books:

1. Venkataraman, K. *Design of jigs, fixtures and press tools*. John Wiley & Sons, 2015.
2. Jones, Ernest James Henry, and Harold Clifford Town. *Production engineering: jig and tool design*. Newnes, 2013.
3. Reid, D. "Fundamentals of tool design, Society of manufacturing engineers." *Publications development department* (1991).

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED557	Micro- Electro-Mechanical Systems (MEMS)	3	0	0	9

Course Objective

To enable students to obtain real life exposure in fabrication and uses of MEMS technology.

Learning Outcomes

Upon successful completion of this course, students will:

- Understand the benefits and consequences of scaling in MEMS.
- Understand properties and crystallography of each elements of MEMS system.
- Design and understand bulk micromachining and fabrication technologies.
- Understand noise and different challenges in MEMS.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction, material selection and classification, their characteristic features. Concept of scalability, perception of micron-based dimensions and their real-life significances, challenges of scalability and mass manufacturing related to MEMS, case studies.	15	Understanding the concept of MEMS and their special purpose applications.
2	Surface micromachining processes for MEMS fabrication. Inspection, quality control and microscopic analysis of the micro machined products. MEMS based sensors & actuators: Working Principle, sensitivities. Latest applications of those actuators in cell phones,	12	Acquiring awareness of the manufacturing processes related to MEMS. Appreciation of the working principle of various MEMS based devices and their latest applications.

	biomedical instrumentation and aerospace technology, case studies.		
3	Principles of electro mechanics applied in MEMS, mathematical assessment of the sensitivities and electromechanics features of MEMS, Modelling and design techniques for MEMS based devices, preliminary exposure to software used for modelling.	6	Appreciating the mathematical modelling and subsequent assessment of electromechanics features of MEMS and the relevant software.
4	Packaging issues related to MEMS, Reliability assessment and measurement techniques for MEMS, precision, accuracy, uncertainties of MEMS based devices, exposure to distribution fitment for predicting the performance.	6	Acquiring knowledge about packaging challenges and uncertainties related to MEMS.

Text books:

1. MEMS, N. P. Mahalik, Tata McGraw-Hill Publications, 2007
2. MOEMS: Micro-Opto-Electro-Mechanical Systems, M. Edward Motamedi, SPIE Publications, 2005

Reference books:

1. MEMS: Introduction and Fundamentals by Mohamed Gad-el-Hak
2. MEMS mechanical sensors by Stephen Beeby
3. Microsensors, MEMS, and smart devices by Julian W. Gardner, V. K. Varadan, Osama O. Awadelkarim
4. MEMS and microsystems: design, manufacture, and nanoscale engineering- Tai-Ran Hsu
6. Micromachining – V.K.Jain, Narosa Publishing house

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED558	Micro Manufacturing	3	0	0	9

Course Objective
Principle of mechanics of manufacturing in macro and micro are entirely different. Materials change behaviour if processed at micro level. The present course based on the mechanical/chemical behaviour changes during

micromachining/manufacturing. Therefore, tool based micro machining and unconventional micromachining processes have been explored.
Learning Outcomes
Upon successful completion of this course, students will: • Learn the fundamental and process mechanics of micromachining. • Understand of mechanics at micro level machining. • Able to Differentiate between micro and macro machining, visualize micro machining process. • Understand application and advancements in the micro machining process.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction and classification of micromachining; Mechanical type micro machining processes: Abrasive jet micromachining (AJMM), Ultrasonic micromachining, abrasive water jet micro machining (AWJMM)	9	Acquired knowledge about different micro-machining processes.
2	Magnetorheological finishging (MRF), Magnetorheological abrasive flow finishing (MRAFF), Magnetic float polishing (MFP)	7	Acquired knowledge about super finishing processes.
3	Chemical and electrochemical type advanced machining processes: Electrochemical micromachining (EDMM), electrochemical micro deburring, Chemical and photochemical micro-machining. Abrasive based nano finishing processes: Abrasive flow finishing (AFF), Chemo-mechanical polishing (CMP), Magnetic abrasive finishing (MAF)	10	Understanding about the capabilities of different micro-manufacturing processes.

4	Thermo electric type micro-machining process: Electric discharge micromachining (EDMM), wire EDM, EDDG, ELID, Laser beam micro machining (LBMM), Electron beam micromachining (EBMM)	7	Understanding about the capabilities of different advanced micro-manufacturing processes.
5	Traditional mechanical micro-machining processes: Micro turning, micro milling, micro drilling	6	Understanding about the capabilities of traditional micro-manufacturing processes.

Text books:

1. Introduction to micromachining, VK Jain, Narosa Publisher, New Delhi 2nd edition

Reference books:

2. Micromachining methods, JA Mc Geough, Champan and Hall, London
3. Micro manufacturing processes, VK Jain CRC Press
4. Advanced machining processes, VK Jain, Allied Publisher New Delhi

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED559	Micro and Precision Engineering	3	0	0	9

Course Objective
To impart the knowledge about the tooling and job holding requirements during different machining operations. Design considerations for jigs and fixtures for macro and micro components.
Learning Outcomes
Upon successful completion of this course, students will: • Learn about the precision machine tools/ macro and micro components. • Understand handling and operating of the precision machine tools. • Learn to work with miniature models of existing machine tools/robots and other instruments.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction to Microsystems, design, and material selection, micro-actuators: hydraulic, pneumatic, electrostatic/ magnetic etc. for medical to general purpose applications. Micro-sensors based on Thermal, mechanical, electrical properties; micro-sensors for measurement of pressure, flow, temperature, inertia, force, acceleration, torque, vibration, and monitoring of manufacturing systems.	11	Get introduced to the fundamental of micro and precision engineering.
2	Fabrication processes for micro-systems: additive, subtractive, forming process, Examples of microsystems: Micro-pumps, micro-turbines, micro engines, micro-robot, and miniature biomedical devices	10	Acquired a completed idea about fabrication processes for micro-system.
3	Introduction to Precision engineering, Machine tools, holding and handling devices, positioning fixtures for fabrication/ assembly of microsystems. Precision drives: inch worm motors, ultrasonic motors, stick-slip mechanism and other piezo-based devices.	5	Understand about the basic elements of Precision engineering.
4	Precision machining processes for macro components: diamond turning, fixed and free abrasive processes, finishing processes.	6	Acquired a completed idea about the components of Precision engineering.
5	Metrology for micro systems, Surface integrity and its characterization.	7	Understanding about metrological and characterization methods.

Text books:

1. Davim, J. Paulo, ed. *Microfabrication and Precision Engineering: Research and Development*. Woodhead Publishing, 2017
2. Gupta K, editor. Micro and Precision Manufacturing. Springer; 2017

References books:

1. Dornfeld, D., and Lee, D. E., Precision Manufacturing, 2008, Springer.

2. H. Nakazawa, Principles of Precision Engineering, 1994, Oxford University Press.
3. Whitehouse, D. J., Handbook of Surface Metrology, Institute of Physics Publishing, Philadelphia PA,1994.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	MEO585	Quality Engineering and Management	3	0	0	9

Course Objective
The Objective of the course is to improve quality and productivity of products and services in order to compete and excel in the international market

Learning Outcomes

Upon successful completion of this course, students will:

- Be able to understand quality of products and services
- Be able to solve actual quality related problems by using statistical quality control techniques.
- Be able to learn about aspects of quality management techniques.
- Be able to solve problems related to quality management in the industry.
- Be able to understand and use various quality management and associated standards as well as software in the industries.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction to Quality Engineering and Management	1	This unit will help learn basics of quality of products and services.
2	Control Charts: Types, Types of sampling and Acceptance Sampling plans, Normal Distribution curve, Process Capability Analysis.	9	This unit will help students in controlling deviations in the dimensions of quality characteristics of products and processes.
3	Definition and Evolution of quality, Contribution of Deming and Taguchi	6	Understanding of various definitions and history of quality and about quality experts

4	Quality Costs, Quality Function Deployment, Business Process Re-engineering, Quality Management, Total Quality Management: definition, philosophy, principles, vision, mission	7	This unit will help students in understanding quality improvement methodology.
5	Quality tools and techniques - Seven Tools of Quality, Seven Quality Management Tools, Six Sigma, Benchmarking, JIT, Poka-Yoke, 5S Campaign, Kaizen, Quality Circles	7	This unit will help in learning basic statistical tools and various quality management concepts and techniques for application in the industries
6	Management Systems - Quality Management Principles as per ISO 9000, ISO 9001, ISO 14001, ISO 45001, their importance and case studies, introduction to SPSS/TQM Software.	9	This unit will help students to learn about international quality, environmental as well as occupational health and safety management standards and SPC/TQM software in order apply in the industries.

Text books:

1. ‘Statistical Quality Control’, by D. C. Montgomery. John Wiley & Sons, Inc., 7th Ed. 2013
2. ‘Total Quality Management’, Dale H. Besterfield et al, Pearson Education Reprint 2011

References books/ Standards:

3. ISO 9000: 2015 Quality Management System-Fundamentals and Vocabulary
4. ISO 9001:2015 Quality Management System- Requirements with guidance for use
5. ISO 14001: 2015 Environmental Management System- Requirements with guidance for use
6. ISO 45001:2018 Occupational Health and Safety Management System - Requirements with guidance for use for use

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	MEO586	Additive Manufacturing	3	0	0	9

Course Objective
To provide detailed understanding of additive manufacturing processes. The prospect of future research will also discuss in the course which will encourage the PG students to carryout research in the advance area,
Learning Outcomes
Upon successful completion of this course, students will: • Broad understanding of Additive Manufacturing processes using different technologies. • Students will be able to think about the possibility of combining different process to develop more efficient AM process. • It will help the students to select the best process among various alternative.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction to Additive Manufacturing and classification. Applications of additive manufacturing in rapid prototyping, rapid manufacturing, rapid tooling, repairing and coating.	4	Understanding the evolution and need of AM processes. It will develop the ability of select the process for particular application.
2	Introduction to 3D-printing, Stereolithography apparatus (SLA), Fused deposition modelling (FDM), Laminated Object Manufacturing (LOM))	6	Understanding the basic principle of curing type, extrusion and layer deposition type AM processes. The students will learn the pros & cons of these processes and their applications.
3	Selective deposition lamination (SDL), Ultrasonic consolidation, Selective laser sintering (SLS), Laser engineered net shaping (LENS), Electron beam free	12	Understanding of thermal based AM processes (UMP). The students will learn the importance of controlled

	form fabrication (EBFFF), Electron beam melting (EBM), Plasma transferred arc additive manufacturing (PTAAM), Tungsten inert gas additive manufacturing (TIGAM), Metal inert gas additive manufacturing (MIGAM).		high energy source to manufacture the complex profile components.
4	Pre-Processing in Additive Manufacturing: Preparation of 3D-CAD model, Reverse engineering and Reconstruction of 3D-CAD model, Part orientation and support generation, STL Conversion, STL error diagnostics, Slicing and Generation of codes for tool path, Surface preparation of materials.	11	The students will understand the use of pre requirement of AM process. Basic knowledge about the software requirement and processing of drawing.
5	Post-Processing in Additive Manufacturing: Support material removal, improvement of surface texture, accuracy and aesthetic; property enhancements.	6	The students will learn about the post processing requirements of different AM processes.

Text books:

1. Gibson, I, Rosen, D W., and Stucker, B., Additive Manufacturing Methodologies: Rapid Prototyping to Direct Digital Manufacturing, Springer, 2015

Reference books:

1. Chee Kai Chua, Kah Fai Leong, 3D Printing and Additive Manufacturing: Principles and Applications: Fourth Edition of Rapid Prototyping, World Scientific Publishers, 2014
2. Chua C.K., Leong K.F., and Lim C.S., "Rapid prototyping: Principles and applications", Third Edition, World Scientific Publishers, 2010
3. Gebhardt A., "Rapid prototyping", Hanser Gardener Publications, 2003
4. Liou L.W. and Liou F.W., "Rapid Prototyping and Engineering applications: A tool box for prototype development", CRC Press, 2007
5. Kamrani A.K. and Nasr E.A., "Rapid Prototyping: Theory and practice", Springer, 2006
6. Mahamood R.M., Laser Metal Deposition Process of Metals, Alloys, and Composite Materials, Engineering Materials and Processes, Springer International Publishing AG 2018
7. Ehsan Toyserkani, Amir Khajepour, Stephen F. Corbin, "Laser Cladding", CRC Press, 2004

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MED 573	Advanced Optimization Techniques	3	0	0	9

Course Objective
• To understand theory of different optimization methods to solve various types of engineering problems. • To understand physical engineering problem and to construct mathematical formulation towards solving it by selecting proper optimization techniques. • To understand both computer programming and heuristic approaches to solve optimization problems.
Learning Outcomes
Upon successful completion of this course, students will: • have a broad understanding formulation of engineering optimization problem, specially mechanical engg. • have an understanding about solving the real life/ industrial /engineering/ environmental/ social problems using conventional optimization methods, that helps to take decision. • be able to write MATLAB code for single and multivariable engineering problems. • be able to understand and write MATLAB code for nontraditional optimization technique like GA, ANN, fuzzy logic to solve different engineering problems with single objective function and multi-objective function.

Module	Topics	Lecture Hours	Learning Outcome
1	Basic Concepts: optimization problem formulation.	2	Understanding the types and basic concept of engineering optimization problem formulation. Especially real life/ industrial /engineering/ environmental/ social problems.
2	Single variable optimization algorithms: Exhaustive search method, bounding phase method, Interval halving method, Fibonacci method, golden search method, Newton Rapshon method, bisection method, secant method. Formulation of engineering problem	6	This unit discuss about different types of classical single variable optimization algorithms. Student will

	with single variable. Computer programming to solve the single variable problem		learn to write MATLAB code for these algorithms also.
3	Multivariable optimization algorithms: Unidirectional search, direct search methods: simplex search, gradient based methods: Cauchy's Steepest Descent method Formulation of engineering problem with multiple variable. Computer programming to solve Multivariable optimization algorithm	8	This unit discuss about different types of classical multivariable unconstrained optimization algorithms. Student will learn to write MATLAB code for these algorithms also.
4	Constrained optimization algorithms: Linear programming, nonlinear programming penalty function method, method of multipliers, sensitivity analysis, direct search for constrained minimization. Formulation of engineering problem with constrained multiple variable. Related computer Programming.	6	Student will learn constrained optimization algorithms and their computer programming.
5	Nontraditional optimization: Introduction to Genetic algorithm (GA), Artificial Neural Network (ANN), fuzzy logic etc with single objective function. Computer programming, other evolutionary algorithms. Formulation of engineering problem and solve with Nontraditional optimization.	9	This unit demonstrates basics of Nontraditional optimization techniques. Use of Nontraditional optimization like GA, ANN, fuzzy logic with single objective function to solve different engineering problem.
6	Multi-Objective Optimization: Introduction to linear and nonlinear multi-objective problems, Use of Evolutionary Computations to solve multi objective optimization with computer programming in MATLAB	8	This unit demonstrates Nontraditional optimization techniques to solve different engineering problem with multi objective function.

Text Books:

2. Deb, K. Optimization for engineering design: algorithms and examples. Prentice Hall of India, New Delhi. 2nd Edition 2012

Reference Books:

9. K.Deb, Multiobjective optimization using Evolutionary Algorithm. Wiley. 1st Edition, 2001.

10. Rao, S.S. Engineering Optimization: Theory and Practice. Wiley. 3rd Edition, 2014
11. Ravindran, A., Ragsdell, K. M., Reklaitis, G. V. Engineering Optimization: Methods and Applications, Willey, 2nd Edition, 2013
12. Rardin, Ronald L. Optimization in operations research. Prentice Hall.

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	MEO 587	Advanced Manufacturing Systems	3	0	0	9

Course Objective

The course will provide the advances in manufacturing system and their implementation issues.

Learning Outcomes

On successful completion of the course, the students will

- Able to design different plant layouts
- Able to form cells for cellular manufacturing system
- Understand the concept of modern manufacturing systems

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction to Manufacturing systems, Classification of Manufacturing systems. Analysis of single station, assembly line and job shop problems.	6	Understanding the various types of manufacturing systems.

2	Group Technology: Concepts, merits, demerits and applications, Opitz classification system and production flow analysis. Cellular Manufacturing: Principle of cell formations, applications, different methods of cell formations. Case Studies.	12	Appreciating group Technology and Cellular Manufacturing in the perspective of modern day manufacturing processes and their role in the enhancement of the productivities.
3	FMS: Concepts of FMS, components, FMS layouts. Analysis of Flexible Manufacturing systems., CIM: Concepts, applications	11	Understanding the concept of Flexible Manufacturing Process and the application of Computer Integrated Manufacturing System
4	Lean Manufacturing: concepts, implementation methodology, case studies. Agile Manufacturing: Definition, agility, method of implementation, relationship between lean and agile manufacturing. Case Studies.	10	Understanding the concept of Lean and Agile Manufacturing and their applications in a competitive environment with special reference to the case studies.

Text books:

1. Automation, Production Systems, and Computer-integrated Manufacturing, M. P. Groover, Pearson Education, 4th Edition, 2016

Reference books:

1. Materials & processes in Manufacturing, Degarmo, J. T. Black.
2. Lean Manufacturing System & Cell Design, J. T. Black.
3. Cellular Manufacturing Systems Design, planning and control by Singh, N., Rajamani, Divakar