DEPARTMENT OF MECHANICAL ENGINEERING

Course Structure and Syllabi
For
PhD Course of Mechanical Engineering
(Effective from academic year 2021-2022)

INDIAN INSTITUTE OF TECHNOLOGY (ISM), DHANBAD

Dhanbad-826004, Jharkhand

September 2021

Department of Mechanical Engineering
Ph.D. in Mechanical Engineering

First Semester

Course Type	Course Code	Course Name	L	T	P	Credit
DC1	MEC500	Theory of Elasticity	3	0	0	9
DC2	MEC507	Incompressible and Compressible Flow	3	0	0	9
DC3	MEC516	Unconventional Manufacturing Process	3	0	0	9
DC4	MEC503	Numerical Methods	3	0	0	9
DC5	HSI500	Research and Technical Communication	0	0	0	9(S/X)
		Total=				45

Second Semester

Course Type	Course Code	Course Name	L	T	P	Credit
DE1	MED5xx	Departmental Elective-1	3	0	0	9
DE2	MED5xx	Departmental Elective-2	3	0	0	9
DE3	MED5xx	Departmental Elective-3	3	0	0	9
OE2	MEO5xx	Open Elective-2	3	0	0	9
DC6	MEC591	Research Methodology and Statistics	3	0	0	9
		Total=				45

Third Semester

Course Type	Course Code	Name of the Courses	L	T	P	Credit
DC7	MEC594	Basics of Scientific Computing	3	0	0	9
DC8	MEC501	Mechanical Vibration	3	0	0	9
DC9	MEC508	Advanced Heat Transfer	3	0	0	9
DC10	MEC514	Advances in Machining	3	0	0	9

LIST OF DEPARTMENTAL ELECTIVE COURSES

Course Type	**Course Code**	**Name of the Courses**	**L**	**T**	**P**	**Credit**
		Departmental Elective-1				
DE	MED510	Refrigeration and Air-conditioning	3	0	0	9
DE	MED554	Surface Engineering	3	0	0	9
DE	MED503	Finite Element Method	3	0	0	9
DE	MED515	Theory of Metal Forming	3	0	0	9
DE	MED539	Fundamentals of Aerodynamics	3	0	0	9
DE	MED566	Simulation in Maintenance Engineering and Tribology	3	0	0	9
DE	MED557	Micro-Electro-Mechanical-System (MEMS)	3	0	0	9
DE	MED558	Micro-manufacturing	3	0	0	9
DE	MED532	Theory of Plasticity	3	0	0	9

DE	MED545	Turbomachinery	3	0	0	9
DE	MED556	Design of Tools, Jigs and fixture	3	0	0	9
DE	MED565	Nano Technology in Tribology	3	0	0	9
Departmental Elective-2						
DE	MED509	Advanced Thermodynamics	3	0	0	9
DE	MED521	Theory of Lubrication	3	0	0	9
DE	MED529	Composite materials	3	0	0	9
DE	MED555	Computer Aided Manufacturing and Robotics	3	0	0	9
DE	MED542	Finite Element Method in Thermal Engineering	3	0	0	9
DE	MED520	Tribology Based Maintenance Engineering	3	0	0	9
DE	MED541	Microfluidics	3	0	0	9
DE	MED559	Micro and Precision Engineering	3	0	0	9
Departmental Elective-3						
DE	MED538	Gas Dynamics	3	0	0	9
DE	MED519	Engineering Tribology	3	0	0	9
DE	MED531	Fracture Mechanics	3	0	0	9
DE	MED513	Thermo Production Processes	3	0	0	9
DE	MED526	Finite Element Method for Dynamics and Stability Analysis	3	0	0	9
DE	MED546	Conduction and Radiation	3	0	0	9
DE	MED525	Rotor Dynamics	3	0	0	9
DE	MED540	Fundamentals of Aeroacoustics	3	0	0	9
DE	MED550	Combustion and Emission in I.C. Engines	3	0	0	9
OPEN ELECTIVE 2						
OE	MEO586	Additive manufacturing	3	0	0	9
OE	MEO590	Advanced Scientific Computing	3	0	0	9
OE	MEO522	Condition Monitoring of Machines	3	0	0	9
OE	MEO 588	Risk Analysis and Safety	3	0	0	9
OE	MEO593	Bio Fluid Mechanics	3	0	0	9
OE	MEO581	Fundamentals of combustion	3	0	0	9
OE	MED528	Robotics	3	0	0	9
OE	MEO580	Measurements in Thermal Engineering	3	0	0	9

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEC500	Theory of Elasticity	3	0	0	9

Course Objective

- To make students understand the analysis of linear elastic solids under mechanical and thermal loads.
- To provide the foundation for pursuing other solid mechanics courses such as theory of plates and shells, elastic stability, composite structures and fracture mechanics.
- To expose students to two dimensional problems in Cartesian and polar coordinates. 4. To make students understand the principle of torsion of prismatic bars.

Learning Outcomes

Upon successful completion of this course, students will:

- Understand the basic concepts in continuum mechanics of solids, including of strain, internal force, stress and equilibrium in solids.
- Characterize materials with elastic constitutive relations.
- Use analytical techniques to predict deformation, internal force and failure of simple solids and structural components.
- Apply principles of continuum mechanics to design a structure or component to achieve desired performance under realistic constraints.

Module	Topics to be Covered	Lecture Hours	Learning Outcome
1	Introduction of Cartesian tensor analysis, Continuum concept of stress and strain fields, Concept of displacement field, Stress-strain-displacement relationship in polar coordinate system	10	Gives a comprehensive idea about the basic mechanics of elastic response.
2	Generalized Hook's law, Stress equilibrium equation, Compatibility condition, 3-D Mohr's circle and plan stress & strain Problem, Hydrostatic and deviatoric stress tensor, Lame's elastic constant, concept of Airy's stress function approach	10	Understanding the traction vector and stress tensor and Develop the equilibrium equation
3	Formulation and Solution Strategies, Energy Methods	6	Understanding the general formulation of boundary value problem
4	Bending analysis of a beam with shear effect, Effect of thickness ratio on the deflection of beam due to shear, estimation of bending stresses, Plastic analysis of beams	4	Understanding the stress and deflection of general cross-section beam
5	Torsion of circular and non-circular bar (Saint-Venantapproach), Flexural rigidity in an elliptical and triangular bar under torsion.	4	Understanding the behavior of general cross-section bar under Torion
6	Axi-symmetric Problem: Analysis of thick cylinder under internal, external and combined pressure, analysis of Rotating disk using Airy's stress function	5	Understanding the stress and deformation in Axi-symmetric structures

Text Books:

1. Advanced Mechanics of Solids, L. S. Srinath, 2nd Ed. TMH, 2003.

Reference Books:

1. Solid Mechanics, Kazimi, TMH
2. Theory of Elasticity, S. P. Timoshenko & J. N. Goodier, 2nd Ed. McGraw-Hill, 1951

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	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-discharge, Laser and Electron beam, Plasma arc and Ion beam.	12	Understanding of thermal based unconventional processes (UMP). 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

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	**MEC503**	**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
DE	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.

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	**MEC510**	**Refrigeration and Air-conditioning**	3	0	0	9

Course Objectives
To impart knowledge dealing with computation aspects of Refrigeration and Air-conditioning system. This course is essential for design of Refrigeration plant.
Learning Outcomes
Upon successful completion of this course, students will: 1. Illustrate the fundamental principles and applications of refrigeration and air conditioning system. 2. Obtain cooling capacity and coefficient of performance by conducting test on vapor compression refrigeration systems. 3. Present the properties, applications and environmental issues of different refrigerants. 4. Calculate cooling load for air conditioning systems used for various applications. Operate and analyze the refrigeration and air conditioning systems.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction: Definitions brief history and applications, Review of first and second law of thermodynamics, Carnot theorem related to refrigeration	2	Students will know the use of thermal properties in engineering and other applications
2	Air-cycle Refrigeration: Different cycles, advantages and disadvantages, applications in aircrafts	6	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	Vapour Compression Refrigeration: Analysis and performance of basic cycle, cycles with Sub cooling and Superheating, Effects of operating parameters, Multi-pressure and Cascade systems	8	An ability to identify, formulate and solve engineering problems
4	Vapour Absorption Refrigeration: Aqua-ammonia, LiBr-water and three-fluid absorption systems – description and performance analysis	4	Known about the factor affecting the evaporator capacity, condenser capacity with relative the mathematical equation
5	Refrigerants: Classification and nomenclature, Desirable properties, ODP and GWP, Alternative refrigerants	3	The understanding of air properties and relative technical term cooling load in air refrigeration system.
6	Non-Conventional Refrigeration: Principle and operation of Ejector refrigeration system, Thermoelectric refrigerator, Vortex tube or Hilsch tube refrigerator, Pulse Tube refrigerator, Adiabatic demagnetization refrigerator	4	Calculations of cooling load, sensible heat and lateral heat in air conditioning system involve the usage of property equations framed earlier
7	Introduction to Air Conditioning: Psychometric properties and chart, various psychometric processes	4	An ability to design a air-conditioning system
8	Requirements of comfort air-conditioning, Cycles for summer and Winter air-conditioning, bypass and sensible heat factor, fresh air load, ventilation load	4	Air-conditioning system to meet desired needs in different environment condition

9	Estimation of cooling load and heating load and selection of air-conditioning cycles, Different air-conditioning systems	4	The understanding of air properties and relative technical term cooling load in air conditioning system

Text books:

1. C. P. Arora, Refrigeration and air conditioning, Tata McGraw-Hill, 3rd Edition, 2010.

References:

2. R. C. Arora: Refrigeration and Air Conditioning, PHI, 2nd Edition, 2012.
3. Wilbert F. Stoecker and Jerold W. Jones, Refrigeration and air conditioning, McGraw-Hill Inc., US, 2nd Revised Edition, 1982.
4. Roy J. Dossat and Thomas J. Horan, Principles of refrigeration, Pearson, 5th Edition, 2001.
5. Manohar Prasad, Refrigeration and Air Conditioning, New Age International, Revised 2nd Edition, 2009.
6. Anantha Narayana, Refrigeration & Air Conditioning, Tata McGraw-Hill, 4th Edition, 2013.

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

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 Problems, FEM of Thin Plate & Thick Plate, Finite Element Analysis of Shell	6	Understanding the thin structural element with 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 515	Theory of Metal Forming	3	0	0	9

Course Objective
The course will enable the students to understand the basic principles of Metal Forming Theory, to know the various types of forming processes, to know about advanced metal forming methods.
Learning Outcomes
Upon successful completion of this course, students will: • Be able to acquire fundamental knowledge and understanding of metal forming process. • Formulate relevant research problems, conduct experimental and/or analytical work and analyze results using modern mathematical and scientific methods • Be able design and validate technological solutions to defined problems.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction, Theory of Plasticity: stress tensor, hydrostatic & deviator components of stress, flow curve, true stress strain, yielding criteria, yield locus, octahedral shear stress and shear strains, invariants of stress strain, slip line field theory plastic deformations of crystals.	10	Decide yielding of a material according to different yield theory for a given state of stress
2	Plastic Forming of Metals-Forging: Basics of plastic forming & forging, mechanics of metal working, temperature in metal working, strain rate effects, friction and lubrication, deformation zone geometry; Forging process: classification, equipment, calculation of forging loads, forging defects, residual stresses.	7	Understanding the concept and design aspect relevant to Metal forging
3	Plastic Forming of Metals-Rolling and Extrusion: Rolling and Extrusion, classification, rolling mills, rolling of bars & shapes, rolling forces, analysis of rolling, defects in rolling, theories of hot & cold rolling, torque power estimation. Extrusion: classification, equipment, deformation lubrication and defects, analysis, hydrostatic extrusion, tube extrusion.	7	Understanding the fundamental aspects and application of rolling and extrusion process
4	Plastic Forming of Metals- Drawing and Sheet metal forming: Drawing & Sheet Metal Forming, rod & wire drawing equipment, analysis, deep drawing, tube drawing, analysis, residual stresses, sheet metal forming, methods, shearing and blanking, bending, stretch forming, deep drawing, forming limit criteria, defects, press brake forming, explosive forming.	7	Understanding the stress state and its relevance in sheet metal working processes
5	Unconventional Forming Methods: Classification; Process Principle, Applications, Equipments, Process Analysis and Die Design of Explosive Forming; Electro-Magnetic Forming ; Electro-Hydraulic	8	Application to advanced metal forming processes. This module will be useful in selection of different metal forming process in application.

	Forming; Laser Beam Bending and Laser Assisted Deep Drawing; MICRO FORMING PROCESSES: Classification; Process Principle and Applications of Conventional Micro Forming Processes and Unconventional Micro-Forming Processes.		

Text books:

1. Manufacturing Processes for Engineering Materials, Kalpakjian and Schmid, Prentice Hall. 5th edition, 2017
2. Manufacturing Science : Ghosh and Mallick, East-West Press Private Limited

Reference books:

3. George E Dieter, Mechanical Metallurgy, Tata McGraw Hill, 3rd Edition
4. Materials and Processes in Manufacturing, Degarmo, J. T. Black, PHI, Pvt Ltd.
5. Fundamentals of modern manufacturing processes, M. P. Groover.

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 boundary layers	4	Ideas on the elements of hypersonic flows and Newtonian theory, Ideas on the equations of viscous flow, Basic 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	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
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, biomedical instrumentation and aerospace technology, case studies.	12	Acquiring awareness of the manufacturing processes related to MEMS. Appreciation of the working principle of various MEMS based devices and their latest applications.
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
DC	**MED532**	**Theory of Elasticity**	3	0	0	9

Course Objective

- To make students understand the analysis of linear elastic solids under mechanical and thermal loads.
- To provide the foundation for pursuing other solid mechanics courses such as theory of plates and shells, elastic stability, composite structures and fracture mechanics.
- To expose students to two dimensional problems in Cartesian and polar coordinates. 4. To make students understand the principle of torsion of prismatic bars.

Learning Outcomes

Upon successful completion of this course, students will:

- Understand the basic concepts in continuum mechanics of solids, including of strain, internal force, stress and equilibrium in solids.
- Characterize materials with elastic constitutive relations.
- Use analytical techniques to predict deformation, internal force and failure of simple solids and structural components.
- Apply principles of continuum mechanics to design a structure or component to achieve desired performance under realistic constraints.

Module	Topics to be Covered	Lecture Hours	Learning Outcome
1	Introduction of Cartesian tensor analysis, Continuum concept of stress and strain fields, Concept of displacement field, Stress-strain-displacement relationship in polar coordinate system	10	Gives a comprehensive idea about the basic mechanics of elastic response.
2	Generalized Hook's law, Stress equilibrium equation, Compatibility condition, 3-D Mohr's circle and plan stress & strain Problem, Hydrostatic and deviatoric stress tensor, Lame's elastic constant, concept of Airy's stress function approach	10	Understanding the traction vector and stress tensor and Develop the equilibrium equation
3	Formulation and Solution Strategies, Energy Methods	6	Understanding the general formulation of boundary value problem
4	Bending analysis of a beam with shear effect, Effect of thickness ratio on the deflection of beam due to shear, estimation of bending stresses, Plastic analysis of beams	4	Understanding the stress and deflection of general cross-section beam
5	Torsion of circular and non-circular bar (Saint-Venantapproach), Flexural rigidity in an elliptical and triangular bar under torsion.	4	Understanding the behavior of general cross-section bar under Torion
6	Axi-symmetric Problem: Analysis of thick cylinder under internal, external and combined pressure, analysis of Rotating disk using Airy's stress function	5	Understanding the stress and deformation in Axi-symmetric structures

Text Books:

1. Advanced Mechanics of Solids, L. S. Srinath, 2nd Ed. TMH, 2003.

Reference Books:

1. Solid Mechanics, Kazimi, TMH
2. Theory of Elasticity, S. P. Timoshenko & J. N. Goodier, 2nd Ed. McGraw-Hill, 1951

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	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	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.

Departmental Elective-2

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEC509	Advanced Thermodynamics	3	0	0	9

Course Objectives
To make the students conversant with the fundamentals of thermodynamics and to apply the principles to various thermal systems. Novelty: Advanced topics like Exergy analysis of reactive systems and introduction to irreversible thermodynamics are introduced.
Learning Outcomes
Upon successful completion of this course, students will: 1. have a broad understanding of basic concepts of thermodynamics. 2. have a thorough understanding of entropy and be able to estimate rate of entropy generation in different thermal systems undergoing actual processes. 3. be able to apply exergy analysis to both reactive and non reactive systems undergoing thermodynamic cycles or processes and estimate the associated reversible work and irreversibility. 4. be able to apply the thermodynamic property relations to calculate various thermodynamic properties using the measured properties. 5. understand the theory and concept of thermodynamics for non-equilibrium systems.

Modules	Topics	Lecture hours	Learning outcomes
1	Introduction: Review of basic thermodynamics, First law for a closed system, Caratheodory's approach, Uncoupled and coupled systems, General conservation of energy principle for control volume, Transient flow analysis, Charging and discharging of rigid vessels, Transient analysis with boundary work	5	Understanding of basic concepts and applying the conservation of energy principle to both control mass and control volumes, both for steady and transient conditions
2	Second Law of Thermodynamics and Entropy: Physical meaning of Second law, Statement of Second law, External and internal irreversibility, Introduction to entropy, its statistical interpretation, Caratheodory's axiom II, Entropy balance equation for closed system and control volume. Entropy measurement and its evaluation, Mechanism of entropy generation: Heat transfer across finite temperature difference, Flow with friction, Mixing. Entropy generation number	5	This unit will help the students to understand the limitations of first law and how 2nd law will be useful in overcoming the same. The student will be able to apply the entropy balance to both closed and open systems with view to estimating the related entropy generation in various engineering devices
3	Exergy: Introduction, Availability and exergy of systems Availability or exergetic efficiency, Generalized exergy analysis	8	This unit will make the student understand the concept of exergy and to estimate the

			available and unavailable part of any low grade energy source
4	Thermodynamic Property Relations: Introduction, The Maxwell's relations, The Gibbs and Helmholtz relations, The Clapeyron Equation, General relations involving enthalpy, internal energy and entropy, Co-efficient of volumetric expansion, Isothermal compressibility. Joule Thomson coefficient, Jacobeans' in Thermodynamics	8	This chapter will familiarize the students with thermodynamic property relations, using which the student will be able to estimate different calculated thermodynamic properties from the measured ones
5	Non-Reactive Gas Mixtures: Introduction, basic definitions for gas mixtures, PVT relationship for mixtures of ideal gases, entropy change due to mixing	4	This will help the students to calculate various thermodynamic properties of homogeneous gas mixtures from the known properties the constituents
6	Reactive Gas Mixtures: Introduction, fuels and combustion, theoretical and actual combustion processes, enthalpy of formation and enthalpy of reaction, adiabatic flame temperature, first and second law analysis of reacting systems, Chemical exergy	5	Upon successful completion of this chapter student will be able to apply 1st and 2nd law to reacting systems and to estimate the heat reaction, adiabatic flame temperature etc
7	Irreversible thermodynamics: Introduction to irreversible thermodynamics, Onsager's reciprocal theorem	4	This chapter will help the student understand the theory and concept of thermodynamics for non-equilibrium systems

Text Books:

1. Kenneth Wark, McGraw-Hill, Advanced thermodynamics for engineers, 3rd Edition, 2013.

References:

2. D. E. Winterbone and Ali Turan, Advanced Thermodynamics for Engineers, 2nd Edition, Elsevier, 2015.

3. Sonntag, Borgnakke and Van Wylen, Fundamentals of Thermodynamics , 7th Edition, John Wiley & Sons, 2009.

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEC521	Theory of Lubrication	3	0	0	9

Course Objective
Objective of this course is to understand the fundamental of lubrication and mechanics of different lubrication regimes and to develop ability to solve various tribological problems in Industry related to lubrication.
Learning Outcomes
Upon successful completion of this course, students will: • have a broad understanding of theory of lubrication. • be able to determine the performance parameters of hydrodynamic bearings, squeeze film bearings, Hydrostatic bearings. • be able to understand lubrication of rolling element bearings. • be able to solve lubrication issues of industry.

Module	Topics	Lecture Hours	Learning outcomes
1	Lubrication regimes, Viscosity and the rheology of lubricants. Mechanics of Lubricant Film: Momentum equation, Navier-Stokes equation, Continuity equation, Energy equation, Reynolds equation, Lubricant flow, Shear forces, Reynolds equation for power law fluids.	7	Basic concept of theory of Lubrication and related equations.
2	Hydrodynamic Lubrication: Hydrodynamic Thrust Pad Bearing (ILA and ISA), Hydrodynamic Journal Bearing (ILA & ISA), Finite Bearing, Mechanism of hydrodynamic instability, Dynamic characteristics of hydrodynamic journal bearings.	12	Ability to analyze and design hydrodynamic sliding element bearing
3	Squeeze film Lubrication : Squeeze film of planer, non-planer, and finite surfaces.	5	Understanding of squeeze film lubrication and its application
4	Hydrostatic Lubrication: Circular step externally pressurized thrust bearing (capillary and orifice compensated), Externally pressurized multi-recess journal bearing with short and large sill dimensions.	7	Ability to analyze and design different types of hydrostatic bearings
5	Elasto-hydrodynamic Lubrication: Introduction, EHL under Line and Point contact, Different regimes in EHL contacts, Mixed Lubrication.	8	Understanding of Elastohydrodynamic lubrication in different machine components

Text Books:

1. Theory of Lubrication : Ghosh , Mazumdar, and Sarangi, Tata McGraw Hill Education.; 1st edition , 2013

Reference Books:

1. Applied Tribology- Bearing Design and Lubrication: M M Khonsari and E R Booser, John Wiley & Sons; 3rd edition, 2017
2. Engineering Tribology by GwidonW. Stachowiak and Andrew W. Batchelor, 4th Edition, 2014.
3. Fundamental of Fluid Film Lubrication: B J Hamrock, S R Schimid, and B O Jacobson, Marcel DekkerInc. 200

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	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	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, connectivity and assembly for equations with multiple degrees-of-freedom	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 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
DC	MEC520	**Tribology based Maintenance Engineering**	3	0	0	9

Course Objective
The objective of the course is to impart knowledge of maintenance Engineering to students in order to help industries solve maintenance related problems .
Learning Outcomes
Upon successful completion of this course, students will: • Be able to understand basics of maintenance engineering. • Be able to learn various types of maintenance. • Be able to learn about various tests and analyses for maintenance • Be able to know about lubricants used in maintenance of machines. • Be able to solve problems related to maintenance of machines in the industries by use of maintenance software

Module	Topics	Lecture Hours	Learning Outcome
1	Maintenance: Key to reliability and productivity, Basic elements of maintenance system - inspection, planning & scheduling, job execution, record keeping, learning & improvement, Data collection and analysis	5	This unit will help learn basics of tribology based maintenance engineering.
2	Basic definitions - preventive, operating and shutdown maintenance; Condition based maintenance and condition monitoring. Application of preventive maintenance for system of equipment, Bath tub curve	6	This unit will help students in gaining knowledge about various types of maintenance.
3	Vibration and signature analysis; causes, remedy in rotating machinery, Fluid analysis for condition monitoring, various methods of fluid analysis.	7	Understanding of various analyses for maintenance.
4	Non-destructive test: dye-penetrant test, magnetic particle test and ultrasonic tests.	4	This unit will help students in learning about types of tests
5	Science of friction and wear, Different types of wear	7	This unit will help in learning about friction and wear.
6	Lubrication: Introduction to lubrication engineering, types, classification of lubricants with their properties and characteristics. Bearing lubrication technique for minimization of friction and wear.	7	This unit will help students to learn about lubricants and additives, their properties and applications.
7	Introduction to computer-aided maintenance management system (CMMS). CMMS Software, Case studies	3	This unit will help students to learn about real life situations and application software.

Textbook

1. Introduction to Maintenance Engineering: Modeling, Optimization, and Management Mohammed Ben-DayaUday Kumar D.N. Prabhakar Murthy 2016 John Wiley & Sons, Ltd.

Reference Book/software.

2. Maintenance Engineering Sushil Kumar Srivastava 2010 S. CHAND Publishing

CMMS Software

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, 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	12	They will learn the basic fluids mechanics and mathematic used for the analysis of microfluidics.
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	12	In this module different microfluidics devices and their

	actuators; Biomicrofluidics, Lab-on-chip devices; Micro-total-analysis systems (μ-TAS)		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	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
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	**MED519**	**Engineering Tribology**	**3**	**0**	**0**	**9**

Course Objective
To understand the application of Tribology in modern machinery for designing, manufacturing and exploration for new and better products.
Learning Outcomes
Upon successful completion of this course, students will: • Be able to know the field of tribology. • Be able to know the surface, properties of surface and related instruments • Be able to understand the friction, friction theory and behaviour of metals and non-metals • Be able to understand wear processes, wear theory, behaviour of metals and non-metals and different instruments • Be able to understand the lubricants, lubrication and instruments for measuring lubricant's properties.

Module	Topics	Lecture Hours	Learning Outcome
1	Introduction: Friction, Wear and Lubrication.	2	Introduce the students to the field of tribology
2	Engineering Surfaces – Properties and Measurement; Typical surface layers, Measurement Methods (Surface Profilometry, Optical Microscopy, Electron Microscopy), Surface Contact.	6	Students will learn about the surface, properties of surface and related instruments.
3	Friction: Measurement Methods, Adhesion, Deformation, Friction Theories, Stick-slip, Rolling Friction, Friction of Metals, Friction of Non-Metallic Materials.	7	Students will learn basic understanding of friction, become familiar with common friction theory and friction behaviour of metals and non-metals.
4	Wear: Types of Wear and its Mechanisms (Adhesive Wear, Abrasive Wear, Erosive Wear, Corrosive/Oxidative Wear, Fatigue Wear), Wear of Metals, Wear of Ceramics, Wear of Polymers, Wear Test (Pin on Disc Tribometer, Reciprocating Tribometer), Wear reduction methods.	10	Students will learn basic understanding of wear processes, wear theory, wear behaviour of metals and non-metals and learn different instruments for measuring friction and wear.
5	Lubricants and Lubrication: Lubricants and their types, Purpose of Lubrication, General Properties of Liquid Lubricants, Animal and Vegetable Oils, Mineral oils, Synthetic oils, Blended Oils, Lubricant Additives, Semi Solid Lubricant or Greases, Solid Lubricants, Testing of Lubricants (Viscometer, Four Ball Tester).	10	Students will learn basic understanding of lubricants, lubrication and learn different instruments for measuring lubricant's properties.
6	Case studies on friction, wear and lubrication using ANSYS.	4	Students will learn the behaviour of tribological components by software.

Textbooks

1. Engineering Tribology, Gwidon W. Stachowiak and Andrew W. Batchelor, 4^{th} Edition,2014
2. Tribology: Friction and Wear of Engineering Materials, Ian Hutchings and Philip Shipway, 2^{nd} Edition, 2017

References

1. Introduction to Tribology , Bharat Bhushan, Wiley, 2nd Edition, 2002
2. Engineering Tribology by. Prasanth Sahoo, Prentice Hall India Learning Private Limited, 2005
3. Fundamentals of Tribology, Ramsay Gohar and Homer Rahnejat, Imperial College Press, 2nd Edition, 2012

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	**MED 513**	**Thermo Production Process**	**3**	**0**	**0**	**9**

Course Objective
The course will enable the students to have sound theoretical and practical knowledge related to coalescence, foundry and Powder Metallurgy related practices in manufacturing domain.
Learning Outcomes
Upon successful completion of this course, students will: • Be able to have fundamental knowledge on basic manufacturing processes. • Have basic understanding of each manufacturing process parameters and its optimization procedure. • Be able to select a different manufacturing process based on requirement. • Be able to design and develop a product from scratch using commonly available raw materials. • Be capable of formulating governing equation from first principals and analyse the results.

Module	Topics	Lecture Hours	Learning Outcome
1	Metal Casting sand, Properties and Testing of Moulding Sand; Design of Pattern and Core, Gating System Design, Mould filling velocity and time including friction and velocity distribution in the conduit. Determination of solidification time of castings; Riser design and Placement.	10	Understanding the relevant properties of molding sand, gating system. Learning of the solidification time and riser design related fundamentals.
2	Casting defects, Miscellaneous casting: Dry sand casting, investment casting, pressure die casting, centrifugal casting and continuous casting. Application of reverse engineering in metal casting.	5	Appreciation of the different classes of defects and knowledge acquisition of various casting methodologies including the understanding the application of reverse engineering through casting.
3	Welding processes: Principle and type of fusion welding processes, modes of metal transfer, heat flow characteristics, welding power supply characteristics-conventional and pulsed power sources, inverter type; Modelling of welding processes.	8	Acquiring knowledge about the various types and principles of popular processes of coalescence. Appreciating the relevant characteristics of power sources relevant for welding.
4	Special welding processes; Electron Beam Welding, Laser Beam Welding, Friction Stir Welding, Explosive welding and Ultra-sonic welding, Weldability of cast iron, plain carbon and low alloy steels, stainless steels, Defects and Inspection of welds- NDT; Case studies.	6	Appreciation of the revances and functioning of various modern welding process like friction stir welding, EBW, USW etc. Understanding the weldability of materials and various welding defects.
5	POWDER METALLURGY: Introduction, Sintering, Densification and Sizing; Impregnation and Infiltration. Isostatic pressing, Hot pressing and Spark plasma sintering. Porous metals and metal foams, concept of atomisation.	10	Acquiring knowledge related to various aspects of Powder Metallurgy process and their applications.

Text books:

1. Manufacturing Engineering and Technology, Kalpakjian and Schmid, Pearson Publishers, 7^{th} Edition, 2014

Reference books:

1. Materials and Processes in Manufacturing, Degarmo, J. T. Black, Prentice Hall of India Pvt Ltd.
2. Fundamentals of modern manufacturing processes, M. P. Groover.
3. Manufacturing Science : Ghosh and Mallick, East-West Press Private Limited
4. Machining and Metal Working Handbook, Ronal A Walsh and Denis Cormier McGraw Hill Publication.

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	**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	**MCD525**	**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	**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,	7	To understand the concepts tonal and broadband noise, some basics of anechoic chamber, calibration procedure of anechoic

	calibration procedure, acoustic sensors, aero-acoustic measurements		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	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	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

	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		
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	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 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).	12	Understanding of thermal based AM processes (UMP). The students will learn the importance of controlled 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

Ehsan Toyserkani, Amir Khajepour, Stephen F. Corbin, “Laser Cladding”, CRC Press, 2004

Course Type	Course Code	Name of Course	L	T	P	Credit
OE	**MEO590**	**Advanced Scientific Computing**	3	0	0	9

Course Objectives

- To given an idea on the various methods of high accuracy numerical solution in diverse application areas.
- To introduce the concept of global spectral analysis (GSA) in developing high accuracy methods.
- To demonstrate how to avoid and minimize non-physical q-waves, aliasing errors, error due to Gibbs' phenomenon while performing high accuracy numerical solutions.
- To highlight and emphasize the correct error dynamics as obtained from GSA.

Learning Outcomes

1. Students will perform exercise related to resolution by GSA.
2. GSA will enable students to characterize numerical methods based on stability properties, numerical phase speed and group velocity. Students will analyze various numerical schemes via their numerical dispersion relation.
3. Developing compact schemes for uniform/non-uniform grids will be taught and exercises will be given.
4. Dispersion relation preserving (DRP) schemes will be developed using numerical dispersion relation.
5. GSA of convection-diffusion-reaction equation will be performed for related problems of combustion.
6. Long-time, high accuracy solutions require avoiding focusing error, aliasing error, Gibbs' phenomenon. Focusing is explained as due to various sources including anti-diffusion. This will be learnt via solving canonical problem with Navier-Stokes equation.

Modules	Topics	Lecture hours	Learning outcomes
1	Basics of Governing equations	3	Primitive and derived variable formulations are described.
2	Space-time discretization for PDEs	2	Emphasis will be on dispersion relation of space-time discretization.
3	Waves: Hyperbolic and dispersive waves	2	With the dispersion relation, various hyperbolic and dispersive waves as the building block of fluid flow and wave phenomena are described.
4	Space-time scales in flows	2	Emphasis is on description of fluid flow by time-averaged and unsteady form.
5	Direct numerical simulations (DNS) and large eddy simulations (LES)	3	The fundamentals of high accuracy computing used to explain DNS and LES with emphasis on numerical methods.
6	Global spectral analysis (GSA)	3	Concepts of error dynamics for high accuracy explicit/implicit methods using uniform and non-uniform grids are explained.
7	Time discretization and dispersion relation preserving (DRP) schemes for fluid flow and acoustics	5	Replacing the von Neumann analysis by GSA is explained. Error dynamics of convection equation explained with the help of *p*- and *q*-waves.

8	GSA of convection-diffusion equation	3	This will provide the linearized form of Navier-Stokes equation allowing GSA to explain the concept of anti-diffusion.
9	Focusing of steady/unsteady Navier-Stokes equation	2	Consequence of anti-diffusion is explained for the solution of Navier-Stokes equation explaining the concept of focusing.
10	GSA of convection-diffusion-reaction equation	2	This is the linearized version of governing equations for combustion, allowing GSA and error dynamics to be performed for problems of combustion.
11	Grid generation	2	Solving problems of complex geometry requires this topic. Methods of grid generation explained based on solution of PDE etc.
12	Solution of Navier-Stokes equation	10	High accuracy solution of Navier-Stokes equation in the application areas of transition to turbulence, acoustics and combustion are described.

Text Books:

1. ***High Accuracy Computing Method:*** *Tapan K. Sengupta (Cambridge Univ. Press, New York 2013).*

Reference Books:

1. ***Computational Fluid Dynamics: (Vol. 1 and 2)*** *C. Hirsch, Wiley, 1988*
2. ***Computational Aerodynamics and Aeroacoustics.*** *T. K. Sengupta and Y. G. Bhumkar, Springer Nature, Singapore (2020).*
3. ***High-Performance Computing of Big Data for Turbulence and Combustion (2019)*** *Springer Nature, Switzerland. [Eds: S. Pirozzoli and T. K. Sengupta].*
4. ***DNS of Wall-Bounded Turbulent Flows: A First Principle Approach.*** *T. K. Sengupta and Swagata Bhaumik, Springer Nature, Singapore (2019).*
5. ***Journal papers, reports and thesis.***

Course Type	Course Code	Name of Course	L	T	P	Credit
DC	MEO522	**Condition Monitoring of Machines**	3	0	0	9

Course Objective
The objective of the course is to study the Basics of condition monitoring techniques and the signal processing techniques associated with the instruments used in vibration monitoring, oil analysis etc., its application in industries, case studies related to the condition monitoring of machines and its advantages.
Learning Outcomes
Upon successful completion of this course, students will: • Be able familiar to condition monitoring technique and its methods. • Be able to identify the instruments which may be employed for diagnosis of failures. • Be able to understand diagnose the failures and its consequences and therefore importance of condition monitoring techniques. • Be able to use the instruments and basic signal processing terminology used while handling the instruments. • Be able to diagnose a particular failures and will be able to reach to root cause of the failures in machines.

Module	Topics	Lecture Hours	Learning Outcome
1	Maintenance and Condition Monitoring: Importance and necessity of maintenance, Different maintenance strategies	5	This will familiarise with condition monitoring and its importance in industries.
2	Techniques of condition monitoring: Different Nondestructive techniques – Visual, Dye Penetration, Acoustic Emission and its applications, X-ray, Radiographic, Magnetic Flux test, Temperature monitoring, Vibration analysis, Oil analysis	4	This unit will help students in understanding the basic condition monitoring techniques prevailing in the industries.
3	Oil Analysis – Oil degradation analysis, Abrasive Particle in oil, counters, Particle classification and counter, Spectrometric oil analysis, Performance trend monitoring – Primary and secondary parameters, Ferrography, Corrosion monitoring techniques	10	This will give in an insight of the oil analysis, it parameters used to observe, instruments used in oil analysis.
4	Vibration Measurement – Different sensors for sound and vibration measurement, Data acquisition, Noise and vibration analyzers, Laser vibrometer, Vibration limits & Standards	5	This unit will help students in understanding the basic instruments, basic characteristics and their applications in industries.
5	Basic signal processing techniques: Fourier analysis, Hilbert Transform, Cepstrum analysis, Digital filtering, Time-frequency analysis, Shock pulse method, Kurtosis.	5	This chapters will familiarise students with various signal processing terms used in the vibration analysis during data acquisition and its post processing techniques.
6	Condition monitoring of rotating machines: Bearing condition monitoring, gear condition monitoring, Critical speed analysis, Orbit Analysis, Wear behaviour monitoring, Faults in reciprocating machines, Case studies and failure analyses	10	This chapter will help the students to understand the in-depth analysis of the failures of bearings, wear, gears etc.

Text Books:

1. Robert Bond Randall, Vibration based condition monitoring: Industrial aerospace and automotive applications: Willey publication 2010.
2. Cornelius Scheffer, Paresh Girdhar (2004), Machinery Vibration Analysis & Predictive Maintenance, Elsevier Publication

Reference Books:

1. Rao, B. (1996), Handbook of condition monitoring, Elsevier advanced technology, Oxford.
2. Amiya Ranjan Mohanty, Machinery Condition Monitoring and Principles.(1st edition) 2014Computational Fluid

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

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 593	Biofluid Mechanics	3	0	0	9

Course Objective:

The objectives of this course are:

- To understand the application of fluid mechanics principles to major human organ systems.
- To understand and integrate fluid mechanics engineering concepts to comprehend the biological flows in the human body.
- To understand the underlying fluid mechanics employed in the diagnostic and treatment methods used in the clinical practice.

Course Outcomes

Upon successful completion of this course, students will:

- Understand the physiology and anatomy of biological systems.
- Formulate the problems related to fluid mechanics in human body system and solve by engineering concepts.
- Identify specific diseases in the human body and how fluid mechanics is involved in disease progression.
- Have the capability to carry out a research project based on the real biomedical problems with a perspective towards the design and development of new medical devices.

Unit No.	Topics to be Covered	Lecture Hours	Learning Outcome
1	Review of fundamental fluid mechanics, Biorheology (Constitutive equations. Non-Newtonian fluid models: Power-law fluid, Bingham Plastic fluid, Casson's fluid, Blood: Physical properties and viscous behavior of blood), Blood vessel mechanics	6	At the end of this module, students will be familiarized with basic fluid mechanics and its application to biofluids, Understanding the behavior of Newtonian and Non-Newtonian fluids and the role of various dimensionless numbers in biofluid mechanics, Understanding of hematology and blood rheology, Formulation and explanation of rheological models of the blood.
2	Circulatory system physiology. Function of circulatory system, circulation in heart, Hemorheology, Models for blood flow: Steady flow in tubes, Oscillatory Flow in a rigid tube, Pulsatile flow in a rigid and elastic tube, Wave propagation in elastic tubes. Flow within curved vessels: secondary flows (Dean vortices and Lyne vortices), flow separation and recirculation, wall shear stress (WSS), oscillatory shear index (OSI), Applications in circulatory system: Flow hemodynamics in diseased arteries: stenosis and aneurysms. Heart-valve hemodynamics: Hemodynamic flow across an aortic valve.	11	At the end of this module, students will gain insights regarding the blood circulation system and different types of models used to study the blood flow in arteries, veins and capillaries. Understanding the flow dynamics through blood vessels and heart valves. Understanding the changes in blood flow through diseased arteries.
3.	Flow and mass transport in biological systems. Steady and unsteady state diffusion in dilute as well as concentrated solution, Trans-vascular and transmembrane transport, Mass transport and	11	At the end of this module, students will be familiarized with the transport mechanisms behind various solutes and solvents, which are responsible for cellular metabolism and

	biochemical interactions in tissues, Transport of gases between blood and tissues.		energy generation inside the human body
4	Fluid transport in different human organs: Respiratory system physiology, Air flow in the lungs Mechanics of breathing, Synovial joints physiology. Functions, properties and applications of synovial fluid flow. Transport in kidneys, Glomerular filtration and tubular reabsorption. Ocular fluid transport and intraocular flow. *Insilico*, *invitro* and *invivo* case studies related to biofluid mechanics.	11	At the end of this module, students will be acquainted with the fluid flow mechanism in major organs of the human body. Additionally, state of the art research in the field of bio-fluid mechanics will be discussed that can cater the students pursue research in this interdisciplinary field.

Text Books:

1. Chandran, K.B., Rittgers, S.E. and Yoganathan, A.P., 2012. Biofluid mechanics: the human circulation. CRC press.
2. Truskey, G. A., Yuan, F. and Katz, D. F. “Transport Phenomena in biological systems”, second edition, Prentice Hall, 2009.

Reference Books:

1. Kleinstreuer, C., 2016. Biofluid dynamics: Principles and selected applications. CRC Press.
2. Waite, L., 2005. Biofluid mechanics in cardiovascular systems. McGraw Hill Professional.
3. Zamir, M. and Ritman, E.L., 2000. The physics of pulsatile flow (pp. 49-50). New York: AIP Press.

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, 1994.

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

Course Type	Course Code	Name of Course	L	T	P	Credit
DE	MEO 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.

Text Books:

1. Introduction to Robotics by S. K. Saha, McGraw Hill, 2nd Edition, 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
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
DC	**MEC594**	**Basics of Scientific Computing**	3	0	0	9

Course Objectives

- To enable students understand some rudimentary aspects of scientific computing for solving problems encountered by graduate students in computing and post processing of data e.g. interpolation/ extrapolation of data; finding roots of polynomials; linear algebra etc.
- Essence of solving differential equations: Ordinary and partial differential equations (ODE, PDE). This requires knowledge of discretization of differential operators.
- For ODEs, specific attention will be paid to solve stiff differential equations by some special methods.
- For PDEs, the emphasis is on classification and various classical methods of solving parabolic, elliptic and hyperbolic types. Attention will be paid on dispersive and hyperbolic waves.
- As an example in fluid flows, solution of Navier-Stokes equation will be explained by specific methods.

Learning Outcomes

1. The students will perform exercises of fundamental tools related to problems on extrapolation and interpolation. These are useful in designing numerical methods of solving partial differential equations.

2. While ODEs will begin from elementary level, students will learn the intricate features of stiff ODEs, which are absolutely essential for stability analysis, computing combustion problems involving chemical reactions etc.

3. The students will learn about PDEs from classical point of view to modern approaches based on spectral analysis developed in recent times.

4. Performing computational exercises, students would also develop hands on ability to code and solve problems numerically.

Modules	Topics	Lecture hours	Learning outcomes
1	Basics of scientific computing.	2	From a historical perspective, a guided tour will be given to understand the evolution of scientific computing to its present day applications in high performance computing.
2	Interpolation and extrapolation.	2	This will explain methods of performing extrapolation and interpolation as needed in (i) prescribing boundary conditions; (ii) designing numerical methods of complex geometries by overset grid method. An exercise will help students understand the concept.
3	Root finding of polynomials by Newton-Raphson and Secant methods.	1	An exercise by students will help grasp the power of these methods relatively.
4	Discretization for differential equations	3	This will help students learn the discretization of differential operators in space and time.

5	Ordinary differential equations: Regular and stiff ODEs, parasitic error and solution of initial value problem.	5	This will expose students to methods for numerically solving ODEs. Specific attention will be paid for stiff ODEs, which are still in research domain.
6	Linear algebra and solving boundary value problems.	3	The useful tools of linear algebra are introduced in solving boundary value problems.
7	Governing equations using partial differential equations.	2	Governing differential equations using partial derivatives are explained from vector calculus perspectives.
8	Classification of PDEs	2	The students will learn how to classify different PDEs into parabolic, elliptic and hyperbolic types.
9	Waves and disturbances in fluid flow.	3	The students will be exposed to powerful concepts of solving space-time dependent problems with the help of Fourier and Laplace transforms. Concept of dispersion relation is introduced, in terms of hyperbolic and dispersive waves.
10	Classical methods of solving parabolic PDEs	4	This methods have been historically developed in solving problems encountered in fluid flows and heat transfer. Students will perform an exercise using the tools in item 4 in solving a parabolic PDE.
11	Methods of solving elliptic PDEs	5	Starting from classical relaxation methods, newer methods of solving by gradient methods will be taught with one such exercise performed by the students.
12	Solution of hyperbolic PDEs	3	These wave problems are solved numerically by finite difference methods with an exercise helping students appreciate theoretical and numerical aspects.
13	Solution of Navier-Stokes equation	4	Various formulations of this prototypical example of fluid flow problem are described. Various numerical methods that produce accurate solution are shown.

Text Books:

1. **High Accuracy Computing Method:** Tapan K. Sengupta (Cambridge Univ. Press, New York 2013).

Reference Books:

1. **Computational Fluid Dynamics: (Vol. 1 and 2)** C. Hirsch, Wiley, 1988
2. **Numerical Recipes in Fortran 77,** W. H. Press, S. Teukolsky, W. Vetterling and B. Flannery, Cambridge Univ. Press (1992)
3. **NPTEL Lectures on Foundations of Scientific Computing: available for 40 lecture- "hours" at http://nptel.iitm.ac.in/courses/101104013/1**
4. 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
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	**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	6	Students will be able to analyze the radiation heat transfer

	analysis in the presence of an absorbing or emitting gas		
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	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