M.Tech.

IN

MANUFACTURING TECHNOLOGY

CURRICULUM AND SYLLABI

(Applicable from 2023 admission onwards)

तमसो मा ज्योतिर्गमय

Department of Mechanical Engineering
NATIONAL INSTITUTE OF TECHNOLOGY CALICUT
Kozhikode - 673601, KERALA, INDIA

The Program Educational Objectives (PEOs) of M.Tech.in Manufacturing Technology

PEO1	Graduates apply their in-depth and advanced knowledge for fostering skills of analysing, formulating, defining and solving complex manufacturing challenges for productive and successful careers.
PEO2	Graduates demonstrate innovative and independent research work in academia/industry/R&D to enhance the knowledge base in manufacturing technology and to disseminate the knowledge.
PEO3	Graduates exhibit a high level of professionalism, integrity, social responsibility and life-long independent learning ability.

Programme Outcomes (POs) of M.Tech .in Manufacturing Technology

PO1	Independently carry out research/investigation and development work to solve practical problems
PO2	Write and present a substantial technical report/document
PO3	Demonstrate mastery in manufacturing technology at a level higher than the requirements in the appropriate bachelor program.
PO4	Acquire and share in-depth knowledge in the area of manufacturing technology.
PO5	Analyse complex problems critically in the field of manufacturing technology and arrive at optimal solutions.
PO6	Use modern computer/software tools to model and analyse problems related to manufacturing technology.

CURRICULUM

Total credits for completing M.Tech. in Manufacturing Technology is 75.

COURSE CATEGORIES AND CREDIT REQUIREMENTS:

The structure of M.Tech. programme shall have the following Course Categories:

Sl. No.	Course Category	Minimum Credits
1.	Program Core (PC)	26
2.	Program Electives (PE)	12
3.	Institute Elective (IE)	2
4.	Projects	35

The effort to be put in by the student is indicated in the tables below as follows:
L: Lecture (One unit is of 50 minute duration)
T: Tutorial (One unit is of 50 minute duration)
P: Practical (One unit is of one hour duration)
O: Outside the class effort / self-study (One unit is of one hour duration)

PROGRAMME STRUCTURE

Semester I

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	MA6001E	Advanced Engineering Mathematics	3	1	0	8	4	PC
2.	ME6301E	Advanced Machining Science	3	0	0	6	3	PC
3.	ME6302E	Advanced Metrology & Computer Aided Inspection	3	0	0	6	3	PC
4.		Elective 1	3	0	0	6	3	PE
5.		Elective 2	3	0	0	6	3	PE
6.	ME6391E	Manufacturing Technology Laboratory	0	0	3	3	2	PC
7.		Institute Elective Courses	2	0	0	4	2	IE
		Total	17	1	3	39	20	--

Semester II

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	ME6311E	Modern Machining Processes	3	0	0	6	3	PC
2.	ME6312E	Machine Tools-Design & Control	3	0	0	6	3	PC
3.	ME6313E	Industrial Automation & Robotics	3	0	0	6	3	PC
4.	ME6314E	Advanced Materials Processing Technologies	3	0	0	6	3	PC
5.		Elective 3	3	0	0	6	3	PE
6.		Elective 4	3	0	0	6	3	PE
7.	ME6392E	CAD/CAM/CAE Laboratory	0	0	3	3	2	PC
8.	ME6393E	Project Phase I	0	0	0	6	2	PC
		Total	18	0	3	45	22	--

Semester III

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Category
1.	ME7394E	Project Phase II	0	0	0	9*	3	PC
2.	ME7395E	Project Phase III	0	0	0	45	15	PC
		Total	0	0	0	54	18	--

* To be completed during semester break. The number of hours is indicative only, and corresponds to a regular semester. Since the duration of the semester break is shorter, students are expected to devote more time per week. Furthermore, if Project Phase II is done as an internship, the working hours will be governed by the organization in which the internship is done.

Semester IV

Sl. No.	Course Code	Course Title	L	T	P	O	C	Category
1.	ME7396E	Project Phase IV	0	0	0	45	15	PC
		Total	0	0	0	45	15	--

List of Electives

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1	ME6321E	Design of Mechatronics Systems	3	0	0	6	3
2	ME6322E	Six Sigma with Design of Experiments	3	0	0	6	3
3	ME6323E	Additive Manufacturing Technologies	3	0	0	6	3
4	ME6324E	Industrial Machine Vision	3	0	0	6	3
5	ME6325E	Micro and Nano Manufacturing Processes	3	0	0	6	3
6	ME6326E	Advanced Fluid Power Control and Automation	3	0	0	6	3
7	ME6327E	Quality Engineering and Management	3	0	0	6	3
8	ME6328E	Design for Manufacture and Assembly	3	0	0	6	3
9	ME6329E	Design for X	3	0	0	6	3
10	ME6330E	Advanced Joining Technologies	3	0	0	6	3
11	ME6331E	Metal Additive Manufacturing: Technologies and Practice	3	0	0	6	3
12	ME6332E	Machining Dynamics	3	0	0	6	3
13	ME6333E	Laser Material Processing	3	0	0	6	3
14	ME6334E	Computational Metrology	3	0	0	6	3
15	ME6335E	Additive Manufacturing for Medical Applications	3	0	0	6	3
16	ME6336E	Applications of Laser in Manufacturing	3	0	0	6	3
17	ME6337E	Smart Manufacturing Technologies	3	0	0	6	3

List of Institute Electives

Sl. No.	Course Code	Course Title	L	T	P	O	Credits
1	IE6001E	Entrepreneurship Development	2	0	0	4	2
2	ZZ6002E	Research Methodology	2	0	0	4	2
3	MS6174E	Technical Communication and Writing	2	1	0	3	2

MA6001E ADVANCED ENGINEERING MATHEMATICS

Prerequisite: NIL

L	T	P	O	C
3	1	0	8	4

Total Sessions: 52

Course Outcomes:
CO1: Apply the concepts of matrix theory and vector calculus
CO2: Develop the analytic approach for solving differential equations
CO3: Apply the finite difference and finite volume methods for differential equations
CO4: Implement the analytical and computational techniques in engineering problems

Mathematical operations with matrices, system of linear equations, consistency, vector spaces, linear dependence and independence, basis and dimension, linear transformation, projections, orthogonal matrices, positive definite matrices, eigenvalues and eigenvectors, similarity of matrices, diagonalization, singular value decomposition

Vector fields, line integrals. Surface integrals, change of variables, green’s theorem, stokes theorem, and divergence theorem

The ordinary differential equation (ODE), initial value problems and their solution techniques, general solutions of second-order ordinary differential equations, homogeneous and non-homogenous cases, boundary value problem, Sturm-Liouville problem, and system of ODEs. Partial differential equations (PDEs), Cauchy problem, method of characteristics, second-order PDE and classifications, type of boundary conditions, formulation and solution of the heat, wave, and Laplace equations.

Numerical implementation of ODE and PDE with MATLAB/Python: ODE: initial value problem: first order and higher order methods, boundary value problem, shooting method, data-fitting, least-squares, first and higher order numerical methods for scalar transport equation, finite difference methods for heat, wave, and Laplace equations.

Case studies relevant to the program: The acoustic model for seismic waves, diffusion in heterogeneous media, development of flow between two flat plates, welding problem, heat conduction in a solid material, phase field solution to diffusion (Allen Cahn 1D solution), solution to the interaction of two or more molecules with Lennard-Jones Potentials, etc.

References:
[1] Lay, D. C., Lay, S. R., and McDonald, J.J., 2016, Linear Algebra and its Applications. Pearson, USA.
[2] Kreyszig, E., 2011, Advanced Engineering Mathematics, Wiley, India.
[3] Simmons, G. F., 2011, Differential Equations with Applications and Historical Notes, McGraw Hill, USA.
[4] Sneddon, I.N., 2006, Elements of Partial Differential Equations, Dover, USA.
[5] Rao, K. S., 2010, Introduction to Partial Differential Equations, Prentice-Hall, India.
[6] Butcher, J. C., 2003, Numerical methods for Ordinary Differential Equations, Wiley, USA.
[7] Thomas, J. W.,2013, Numerical Partial Differential Equations: Finite Difference Methods, Springer, Switzerland.
[8] Versteeg, H. K., and Malalasekera, W., 2007, An Introduction to Computational Fluid Dynamics: The Finite Volume Method, Pearson, USA.

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ME6301E ADVANCED MACHINING SCIENCE

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyze the influence of tool angles, geometries of single and multipoint tools on cutting performance, define the various tool nomenclatures as per the industrial standards.
CO2: Analyze various cutting forces, cutting temperature, tool failures and recommend proper tool materials, tool geometry and cutting conditions for efficient machining.
CO3: Predict the cutting forces, power requirements in machining based on different analytical models, and based on mechanics of material removal.
CO4: Evaluate the surface characteristics of various machined surfaces and suggest ways to minimize various defects.
CO5: Analyze basic mechanisms of tool based and surface micromachining processes
CO6: Explain latest technologies like hybrid additive manufacturing, ultra-precision machining, etc.

Mechanics of metal cutting; tool geometry-tool angle relationships in ASA, ORS, and NRS, effect of rake, lead and clearance angles; shear angle and its relevance, strain and strain rate in orthogonal cutting, oblique cutting, stress distribution along rake face, theories of Merchant, Lee and Shaffer, Oxley, etc. friction in metal cutting, Inserts-chip groove geometries; nomenclature, selection and applications in turning, milling, drilling, design concepts, new tool geometries, selection of operating conditions, carbide grade design, carbide coatings, ceramic, super hard grade design, effect of cutting variables on forces, tool failure analysis, theories of tool wear, measurement of tool wear, tool life and economics of machining,

Thermal aspects in machining; heat and temperature distribution, modeling of chip formation in metal cutting, modeling of machining characteristics in turning, milling, drilling, grinding, etc., measurement of cutting forces and cutting temperatures, abrasive machining processes, types and characteristics, surface analysis, methods of improving surface characteristics, surface integrity of machined parts, micro hardness and residual stresses.

Micro machining; tool-based micromachining methods, cutting edge radius effect, minimum uncut chip thickness, micro turning, micro milling, unconventional micromachining methods — micro EDM, micro WEDM. Ultra-precision machining; mechanism of material removal, methods and applications, mechanics, applications. nano surface generation, brittle versus ductileregime machining - ductile cutting of silicon wafers, nanometric cutting, chip formation, recent developments, focused ion beam and electron beam machining, hybrid additive manufacturing processes, materials and new developments.

References:
[1] Knight, Winston A., and Boothroyd, G., 2005, *Fundamentals of Metal Machining & Machine Tools*, CRC Press, USA.
[2] Bhattacharya, Amitabha, 2012, *Metal Cutting*, *Theory and Practice*, New Central Book Agency.
[3] Chattopadhyay, A. B., 2017, *Machining and Machine Tools*, John Wiley & Sons, India.
[4] Ghosh, A., and Mallik, A. K., 2014, *Manufacturing Science*, Affiliated East West Press Ltd.
[5] Lal, G.K., 2007, *Introduction to Machining Science*, New age international publishers.
[6] Shaw, M.C., 2012, *Metal cutting Principles*, Oxford Clarendon Press,
[7] Gibson I., Rosen.D.., Stucker B., Khorasani M., 2021, Additive Manufacturing Technologies, Springer Nature, Switzerland.
[8] Jain, V. K., 2012, *Micromanufacturing Processes,* CRC press, USA.
[9] Dornfeld, D., and Lee, Dae-Eun, 2008, *Precision Manufacturing*, Springer, New York.
[10] McGeough, J., 2002, *Micromachining of Engineering Materials*, Marcel Dekker, Inc., NY.
[11] Taniguchi, N., 1996, *Nanotechnology: Integrated Processing Systems for Ultra-precision and Ultra-fine Products*, Oxford University Press Inc., NY.

ME6302E ADVANCED METROLOGY AND COMPUTER AIDED INSPECTION

Prerequisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Explain the basic terms in metrology as per standards
CO2: Calculate the uncertainty of a measurement according to international standards.
CO3: Identify appropriate instruments for measurement of dimensions, geometrical tolerances
CO4: Select appropriate instruments for measurement of surface finish and compute the relevant parameters.
CO5: Evaluate coordinate measurement systems for measurement of geometric parameters
CO6: Apply digital image processing for measurement applications

Measurement Fundamentals
Introduction and review – metrology and mass production, vocabulary - errors, accuracy, calibration, etc.

Measurement Uncertainty
Measurement fundamentals - measurement uncertainty according to gum, type A evaluation, repeated measurements, regression, type B evaluation, calculation of combined standard uncertainty using law of propagation, numerical approach, handling correlated components, expanded uncertainty, uncertainty and resolution, uncertainty and conformity, Monte Carlo simulation.

Dimensional measurement
Errors – thermal, geometric and elastic deformation, geometric dimensioning and tolerancing - necessity, symbols, calculation of straightness, roundness, bonus tolerances. Surface texture measurement - definitions, stylus instruments, filters and cut-off, computation of amplitude, spatial and hybrid parameters, bearing area curve, autocorrelation function, areal parameters.

Computer Aided Inspection
Coordinate measuring machines - basics, constructional features, measurement process, measurement strategy, sampling strategy, measurement uncertainty, articulated arm CMMs - laser trackers. Machine vision- introduction, image acquisition, file formats and compression, imaging geometry, pixel relationships, preprocessing, segmentation, description, recognition, interpretation, case studies.

References:
[1] Kirkup, L. and Frenkel, R. B., 2006, *An Introduction to Uncertainty in Measurement Using the GUM*, Cambridge University Press, UK.
[2] Whitehouse, D., 2002, *Surfaces and Their Measurement*, Hermes Penton Science, London.
[3] Hocken, J., 2012, *Coordinate Measuring Machines and Systems*, CRC Press, Boca Raton.
[4] Demant, C., Streicher-Abel, B., and Garnica, C., 2013, *Industrial Image Processing*, Springer-Heidelburg, New York.
[5] Crowder, S., Delker, C., Forrest, E., and Martein, N., 2020, *Introduction to Statistics in Metrology*, Springer Nature, Switzerland.
[6] Leach, R., and Smith, S. T., 2018, *Basics of precision engineering*, Taylor and Francis, Boca Raton.
[7] Alexander, S., 1992, *Precision Machine Design*, SME, USA.

ME6391E MANUFATURING TECHNOLOGY LABORATORY

Pre-requisites: NIL

L	T	P	O	C
0	0	3	3	2

Total Practical Sessions: 39

Course Outcomes:
CO1: Grind and measure single point tool angles as per ASA.
CO2: Develop manual CNC programs using canned cycles and measure the dimensions.
CO3: Conduct tool life experiments, measure cutting forces and cutting temperature.
CO4: Conduct experiments on CNC EDM, WEDM, etc.
CO5: Familiarize with various advanced machines like Micromachining Centre, CMM, 3D Profilometer, Nanoindenter, SEM, AFM, XRD Machines, etc.
CO6: Conduct microstructure analysis, defect evaluations, NDT tests, etc.

Exercises on abrasive machining processes, measurements in universal measuring microscope, profile projector, metallographic studies using metallurgical microscope, measurement of tool angles and studies of tool wear in inserts using tool maker's microscope, experimental evaluation of cutting forces using dynamometers, studies and experiments on micromachining centre, programming and measurements with CNC coordinate measuring machine, surface texture analysis, experiments on non-destructive evaluation using ultrasonic testers, exercises on virtual instrumentation.

Exercises on CNC manual program and machine the component using CNC machining centre. Conduct studies on nanoindenter, SEM, AFM, 3D optical profiler, RP machines, high speed camera and thermal imager. Studies and experiments on WEDM and EDM. Analysis of surface defects during machining.

List of Experiments

1. Using suitable machine tool grind a single point cutting tool as per ASA, and measure the obtained tool angles.

2. Study the effect of process parameters on the surface roughness of mild steel specimen using CNC EDM & CNC WEDM

3. Write a CNC program (manual) using FANUC codes and machine the component, (production drawing of the part is given). Find out the required machines, cutting tools, cutting parameters and machine the component and measure the dimensions obtained and prepare the measurement chart. Comment on the obtained dimensional tolerances.

4. Measure the cutting forces during turning on lathe using strain guage dynamometer, plot the tool life graph, and comment on the wear patterns observed on tool.

5. Conduct experiments to improve surface finish of cylindrical workpieces, using centreless grinding process. Comment on the selection of the grinding wheel, finish obtained, obtained geometrical accuracies.

6. Measure the specimen for defects given in the workpiece. Find out the measurements and defects using the following instruments;
   (a) Ultrasonic flaw detector
   (b) Articulated arm CMM

7. Metallurgical evaluation of specimen using metallurgical microscope

8. Cutting force measurements using KISTLER dynamometer

9. Study and programming on CNC CMM

10. Study the optical 3D profilometer, high speed camera, thermal imager, nanoindenter

11. Demo of SEM, AFM, XRD and other facilities

References:

[1] Knight, Winston A., and Boothroyd, G., 2005, *Fundamentals of Metal Machining & Machine Tools*, CRC Press, USA.
[2] Venkatesh, V. C., and Chandrasekaran, H., 1987, *Experimental Techniques in Metal Cutting*, Prentice-Hall of India.
[3] Shaw, Milton C., 2004, *Metal Cutting Principles*, Oxford University Press., London.
[4] Juneja, B. L., Sekhon, G. S., and Nitin Seth, 2003, *Fundamentals of Metal Cutting and Machine Tools*, New Age International, India.
[5] Chattopadhyay, A. B., 2017, *Machining and Machine Tools*, Wiley, India.
[6] Rao, P. N., 2010, *CAD/CAM: Principles and Applications*, Tata McGraw Hill, New Delhi.

ME6311E MODERN MACHINING PROCESSES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:
CO1: Analyze and model mechanics of USM, AJM
CO2: Model and develop electrical circuit for EDM and ECM.
CO3: Analyze and compare MRR, flow, heat transfer in beam processes.
CO4: Compare various modern machining processes and select best suitable process for a given application.

Introduction, classification. Mechanical processes: abrasive jet machining- mechanics of material removal. MRR model for brittle materials and ductile materials. Water jet machining- flow equations and MRR models. Abrasive water jet machining- mechanics of MRR, abrasive and water flow equations (2D). Economics of AWJM. Tribology of AJM. Ultrasonic machining-mechanics of metal cutting: grain throwing and hammering models. Vibration characteristics of prismatic bars and exponential horn. Differential equations for various transducer design. Design criteria, FEM modelling and design of USM systems. Economics of USM. Feed mechanism. Mechanical finishing processes: micro and nano finishing processes with smart fluids. Rotary ultrasonic machining.

Electro thermal processes: electro discharge machining, mechanics of material removal, MRR models.
RC, RL, RCL – detailed circuit analysis and PWM and transistor-based power systems. Overdamped, critical damped, underdamped circuit in EDM. Surface roughness models. Servo systems in EDM and its selection. Dielectric systems-flow analysis. Heat transfer models in EDM and its effect on MRR and surface finish. Mathematical modelling and simulation. Wire EDM. Beam processes: laser, electron and ion beams, characteristics of beams and design of optical systems. Modelling of beam processes heat transfer models: gaussian, double, quadruple, egg shaped configuration heat source models. Modelling of beam processes and parametric study and flow modelling in fluid assisted beam processes.

Electro chemical and chemical processes: electrochemistry. Ion transfer kinetics- detailed analysis- Debye-Huckle-Onsager equations. Double layer. Kinematics and dynamics of ECM. MRR equations. Tool design and mathematical modelling. Tool design using FEM. Electrolyte flow analysis. Chemical machining, photo chemical processes. Electrochemical machining, modifications on basic ECM process: electro chemical grinding, electro chemical deburring, electro polishing, electro stream drilling, shaped tube electrolytic machining. Machine learning application in nontraditional machining processes, hybrid machining process.

References:
[1] Anna, Rudawska, 2018, *Abrasive Technology*, Intech Open, United Kingdom.
[2] Jagadish, and Gupta, Kapil, 2020, *AWJM of Engineering Materials*, Springer, Switzerland.
[3] Loan, D. Marinescu, 2004, *Tribology of AJM processes*, WA Publishers, USA.
[4] Mattiat, O. E., 1971, *Ultrasonic Transducer materials*, Springer, New York.
[5] Andreas, W. Momber, and Radovan Kovacevic, 2012, *Principles of Abrasive Water Jet Machining*, Springer, Germany.
[6] Kuila, Saikat Kumar, 2012, *Parametric Analysis of Abrasive Water Jet Machining*, Lambert.
[7] William R. Tyrrell, 1989, *Ultrasonic Machining*, ASM International.
[8] Marcel, Kuruc, 2021, *Rotary Ultrasonic Machining*, Springer, Germany.
[9] Elman, C. Jameson, 2001, *Electric discharge machining*, Society of Manufacturing Engineers.
[10] Gary, F. Benedict, 2017, *Nontraditional Manufacturing Processes*, Routledge.
[11] John Ion, 2005, *Laser Processing of Engineering Materials*, Butterworth-Heinemann.
[12] Charles Lawson Faust, 1971, *Fundamentals of Electrochemical Machining*, Electrochemical Society.
[13] Jain, V. K., 2007, *Advanced Machining Process*, Allied Publishing Pvt. Ltd., India.
[14] Bosez, Goutam Kumar, 2021, *Machine Learning Applications in NC Machining Processes*, IGI Global.

ME6312E MACHINE TOOLS – DESIGN AND CONTROL

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Evaluate specifications and select suitable machine tools for achieving product specifications.
CO2: Design basic machine tool elements.
CO3: Analyze, predict, and minimize vibrations and chatter in machine tools.
CO4: Create and execute CNC part programs for complex geometries.
CO5: Explain the concepts of Industry 4.0 and cyber physical machine tools.

Design principles of metal cutting machine tools: classification, kinematics, layouts. Stepped and step-less regulation of speed and feed, design of speed gear box and feed gear box. Hydraulic drives, pneumatic drives and electrical drives for machine tools. Comparison and selection of drives. Design of machine tool structures – rigidity and strength criteria, power screws, spindles – forces, bearing types (including taper roller bearing), vibration modelling as MDOF and modal analysis, beds – strength, stiffness, and stability criteria, head stock, guideways – box type and linear motion guideways, structure, selection, assembly, and mounting, hydraulic and pneumatic bearing systems. Lubrication systems in machine tools.

Machine tool dynamics: free and forced vibrations. Effect on undeformed chip thickness, rake and clearance angles. Stability analysis, regenerative chatter – analysis and control. Vibration and noise isolation in machine tools, vibration measurement in machine tools.

Types of CNC machine tools. Design considerations of CNC machine tools. Machine control unit (MCU), interpolators, control loops, and system devices, servo drives, ball screws, control strategies – PD, PID, and PI controllers, adaptive control. Machine tool error analysis – detection, sources, compensation strategies. CNC programming – manual part programming, computer-aided part programming. Generation of CNC programming using CAM modules, hands on training in CNC machining simulators

Industry 4.0, future of machine tool design and control. Machine to Machine (M2M) and Internet of Things (IoT) – fundamentals and architecture. Cyber physical machine tools – components, functions, and case studies. Smart manufacturing.

References:
[1] Mehta, N. K., 2012, *Machine Tool Design and Numerical Control*, Tata McGraw Hill, New Delhi.
[2] Suh, S.H., Kang, S.K., Chung, D.H., and Stroud, I., 2008, *Theory and Design of CNC Systems*, Springer, Germany.
[3] Sen, G. C., and Bhattacharya, A., 1973, *Principles of Machine Tools, Vol 2.*, NCB, Calcutta.
[4] Chattopadhyay, A. B., 2017, *Machining and Machine Tools*, John Wiley & Sons, India.
[5] Mehta, N. K., 2015, *Metal Cutting and Design of Cutting Tools*, *Jigs and Fixtures*, McGraw Hill, New Delhi.
[6] Knight, Winston A., and Boothroyd, G., 2005, *Fundamentals of Metal Machining & Machine Tools*, CRC Press, USA.
[7] Koenigsberger, A., 1964, *Design Principles of Metal Cutting Machine Tools*, Pergamon Press, UK.
[8] Acherkan, J. N., 1982, *Machine Tool Design, Vols. 1 to 4*, MIR Publishers, Russia.
[9] Koren, Y., 1983, *Computer Control of Manufacturing Systems*, McGraw Hill, USA.
[10] Marinescu, I., D., Ispas, C., Baboc, D., 2002, *Handbook of Machine Tool Analysis*, CRC Press, USA.
[11] Chaudhery M., H. Daniel R., 2023, *Designing Smart Manufacturing Systems*, Academic Press, USA.

ME6313E INDUSTRIAL AUTOMATION AND ROBOTICS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Explain various concepts, strategies and functions of automation.
CO2: Develop PLC programming for automated systems and analyze various continuous and discrete control systems.
CO3: Identify sensors and actuators for industrial systems and control.
CO4: Develop the kinematic and dynamic model of serial robotic manipulators.
CO5: Design robot trajectories for industrial and service applications

Introduction to automation: mechanization and automation, definition, types of automation, merits and criticism, architecture of industrial automation systems, manufacturing plants and operations: automation strategies, basic elements of automated system, advanced automation functions, levels of automation.

Industrial control systems: process and discrete manufacturing industries, continuous and discrete control systems: an overview of computer process control, fundamentals of automated assembly system, actuators and sensors: fluid power and electrical actuators, piezoelectric actuator; sensors for position, motion, force, strain and temperature.

Introduction to robotics: robotics system, classification of robots, robot characteristics, kinematics for manipulator: frames and transformations, forward and inverse kinematics, DH representation, derivation of forward and inverse kinematic equations for various types of robots, applications of robots.
Introduction to manipulator Jacobian: singularity, Jacobian in force domain, velocity propagation from link to link, static forces in manipulators, introduction to dynamic analysis: Lagrangian formulation, trajectory planning: joint space and cartesian space.

References:

[1] Craig, John J., 2022, *Introduction to Robotics: Mechanics and Control*, Pearson Education, UK.
[2] Saeed, B. Niku, 2019, *Introduction to Robotics, Analysis, Systems and Applications*, John Wiley & Sons, USA.
[3] Spong, Mark W., and Vidyasagar, M., 2008, *Robot Dynamics and Control*, John Wiley & Sons, USA.
[4] Paul, R.P., 1979, *Robot Manipulators Mathematics Programming, Control*, The Computer Control of Robotic Manipulators, The MIT Press, USA.
[5] Schilling, Robert J., 1996, *Fundamentals of Robotics, Analysis and Control*, Prentice Hall of India.
[6] Mittal, R.K., and Nagarath, I.J., 2003, *Robotics and Control*, Tata McGraw-Hill, New Delhi.
[7] Groover, M., and Zimmers, E., 2014, *CAD/CAM-Computer Aided Design and Manufacturing*, PrenticeHall of India,
[8] Shinskey, F.G., 1996, *Process Control Systems – Application, Design and Tuning*, McGraw-Hill, USA.
[9] Groover, Mikell, 2016, *Automation, Production Systems, and Computer-Integrated Manufacturing*, Prentice Hall Press, India.

ME6314E ADVANCED MATERIALS PROCESSING TECHNOLOGIES

Pre-requisites: NIL

Total Lecture Sessions: 39

L	T	P	O	C
3	0	0	6	3

Course Outcomes:

CO1: Explain advances in manufacturing techniques (i.e., in casting, forming, welding and additive manufacturing) for industrial production.

CO2: Explain the methods, materials, and equipment related to casting.

CO3: Analyze material behavior mechanisms during forming.

CO4: Evaluate heat effects on structure property correlations during joining process.

CO5: Identify capabilities and limitations of additive manufacturing processes based on component application and criticality.

CO6: Evaluate the quality and integrity of materials produced using advanced manufacturing techniques.

Casting processes and steps involved, design of patterns, moulds, cores, and gating system, solidification and cooling, shrinkage and machining allowance, overview of traditional casting methods, advances in casting— die-casting, centrifugal casting, investment casting, high-pressure die casting, vacuum casting and lost foam casting, additive manufacturing integrated casting, advanced casting materials, process simulation and optimization, defects and quality control in casting processes, economics of casting and moulding, sustainable metals and green metallurgy.

Theory of metal forming—plasticity, yield criteria, strain rate sensitivity, effect of temperature and friction in forming, classification of metal forming, mechanics of sheet deformation processes—Bauschinger effect modeling, sheet formability and forming limit curve, classification of forming processes, advances in metal forming— superplastic forming, electroforming, hydroforming, laser forming, open and close die forging, non-conventional drawing techniques, incremental forming etc. Evaluation of defects after metal forming, sustainability in metal forming, numerical modelling in metal forming, FEA simulations.

Joining processes: classification; physics, arc characteristics: analysis of metal transfer, welding power sources; high energy density welding processes, solid state welding, friction stir welding; metallurgy of welding: heat flow in welding; residual stresses, temperature distribution; cooling rate; metallurgical transformation in and around weldment, gas metal reactions, design of weld joints, weld quality and testing, welding automation — advances and challenges.

Introduction to additive manufacturing (AM), AM process chain, benefits and comparison with conventional manufacturing, classification of AM processes, AM technologies: vat polymerization, powder bed fusion, material extrusion, material jetting binder jetting, sheet lamination, direct energy deposition, direct write technologies, hybrid AM technologies- key strengths, process, applications, case studies, research and development, materials for AM, powder production and characteristics, issues challenges and defects of AM parts, AM qualification and certification.

References:

[1] Ghosh, A., and Mallik, A.K., 2010, *Manufacturing Science*, Affiliated East-West Press Pvt. Ltd, India.
[2] Heine, R. and Rosenthal, P., 2017, *Principles of Metal Casting*, Tata McGraw Hill, India.
[3] Valberg, H, 2010, Applied Metal Forming Including FEM Analysis, Cambridge University Press, UK.
[4] Robert W Messler, 2004, *Principles of Welding*, WILEY-VCH Verlag GmbH & Co., Germany.
[5] Lancaster, J.F., 1999, *Metallurgy of Welding*, Woodhead Publishing, UK.
[6] Little, Richard L., 2017, *Welding and Welding Technology*, Tata McGraw Hill, India.
[7] Gibson Ian, Rosen David, Stucker Brent, and Khorasani Mahyar, 2021, *Additive Manufacturing Technologies*, Springer, Germany.
[8] Dixit, U.S., and Narayanan, R.G., 2013, *Metal Forming: Technology and Process Modelling*, McGraw-Hill Education, New Delhi.
[9] Dixit, P.M., and Dixit, U.S., 2008, *Modeling of Metal Forming and Machining Processes: by Finite Element and Soft Computing Methods,* Springer, Science and Business Media, London.

ME6392E CAD/CAM/CAE LABORATORY

L	T	P	O	C
0	0	3	3	2

Total Sessions: 39

Course Outcomes:
CO1: Attain expertise in 2D, 3D drafting using various CAD software.
CO2: Ability to do modelling using various FEM software.
CO3: Acquire CNC programing capability to generate CNC codes using various CAM software.
CO4: Expertise in manufacture components using CAM generated codes either through subtractive or additive manufacturing routes and measure the components utilizing advanced measuring equipment.
CO5: Gain proficiency in Robot programing.
CO6: Develop ladder logic diagrams for pneumatic and hydraulic circuits.

Computer Aided Design: demonstration of part modeling, assembly and mechanism modeling.

Finite Element Analysis: static structural analysis, coupled thermal stress analysis, exercise on geometry import and meshing, modal analysis, nonlinear analysis: geometric, material and boundary nonlinearities, transient structural analysis.

Computer Aided Manufacturing & Automation: Manual and CNC programming, generation of CNC codes from CAD geometries, introduction to robot accuracy and repeatability measurements, introduction to components and tools for automation.

List of Exercises Computer Aided Design:
1.Exercises on part modelling (using different software)
2.Exercises on assembly modelling

Finite Element Analysis:
3.Static structural analysis. (using different software)
4.Coupled thermal stress analysis.
5.Modal analysis to obtain natural frequencies.
6.Elasto-plastic analysis.
7.Transient structural analysis.

Computer Aided Manufacturing & Automation:
8.Generation of CNC codes from CAD models, including for sculptured surfaces – Implementation and measurements of fabricated components both subtractive and additive manufacturing routes
9.Design and testing of pneumatics-based automation circuits
10.Robot programming and repeatability & accuracy measurements
11.Experiments with pneumatics/hydraulic circuits

References:

[1] Rogers, D.F., and Adams, J.A., 2017, *Mathematical Elements of Computer Graphics*, McGraw Hill, India.
[2] Zeid, I., 2009, *CAD/CAM: Theory and Practice*, Tata McGraw Hill, India.
[3] Bhatt, N.D., and Panchal, V.M., 2014, *Machine Drawing*, Charotar Publishing House, India.
[4] Popov, E.P., 2000, *Engineering Mechanics of Solids*, Prentice Hall of India.
[5] Thompson, M.K., and Thompson, J.M., 2017, *ANSYS Mechanical APDL for Finite Element Analysis*, Butterworth-Heinemann, UK.

[6] Zienkiewicz, O.C., Taylor, R.L., and Zhu, J.Z., 2013, *The Finite Element Method: Its Basis and Fundamentals*, Butterworth-Heinemann, UK.
[7] ANSYS Mechanical APDL Documentation.
[8] Koren, Y., 2009, *Computer Control of Manufacturing Systems*, Tata McGraw Hill, India.
[9] Groover, M.P., 2015, *Automation, Production Systems, and Computer Integrated Manufacturing*, Pearson Education, UK.
[10] Craig, J.J., 1999, *Introduction to Robotics, Mechanics and Control*, Addison – Wesley, UK.
[11] Esposito, A., 2003, *Fluid Power with Applications*, Pearson Education, UK

ME6393E PROJECT PHASE I

L	T	P	O	C
0	0	0	6	2

Pre-requisite: NIL

Course Outcomes:

CO1: Understand the process of reviewing and recording the literature
CO2: Understand the process of identification of the project problem
CO3: Apply the learning to define the problem and problem environment/boundary conditions
CO4: Develop a focused research learning, presentation and communication

Project Phase I is normally an initiation into the project.

Each student shall identify a topic of interest related to the core/elective courses undergone in the first semester of the M. Tech. programme. He/she shall get the topic approved by the project guide in the concerned area of specialization. The student is expected to conduct a literature survey. A mid semester evaluation shall be done by the guide. At the end of the semester the student shall present the project problem and the related literature in the presence of the duly constituted evaluation committee. Grade will be awarded on the basis of the student's work and presentation.

ME7394E PROJECT PHASE II

L	T	P	O	C
0	0	0	9	3

Course Outcomes:

CO1: Develop a systematic procedure to solve the identified research/industrial problem
CO2: Analyze and Identify a suitable research methodology for solving the problem identified.
CO3: Apply the methods/tools learned to develop algorithms and solve the problem.
CO4: Analyze and interpret the results using tables and figures for visualization
CO5: Compile and construct a report by employing the techniques of academic writing critical analysis, and defend the thesis
CO6: Publish the findings in reputed journals, conferences or apply for patents

Project Phase II can be an extension of Phase I or internship outside during the summer semester break. Students shall continue to work on the problem identified in the project phase I or undergo internship outside. Students shall identify the methodology, apply for a preliminary work. The work should be suitable for communicating to a conference. The student shall submit a report. All the projects will be evaluated by a duly constituted committee.

ME7395E PROJECT PHASE III

L	T	P	O	C
0	0	0	45	15

Course Outcomes:

CO1: Analyze and Identify a suitable research methodology for solving the problem identified.
CO2: Apply the methods/tools learned to develop algorithms and solve the problem.
CO3: Analyze and interpret the results using tables and figures for visualization
CO4: Compile and construct a report by employing the techniques of academic writing critical analysis, and defend the thesis
CO5: Publish the findings in reputed journals, conferences or apply for patents

The project work can be carried out at the institute or in an industry/research organization. Students desirous of carrying out project work in an industry or in other organizations have to fulfill the requirements as specified in the "Ordinances and Regulations for M. Tech." The student is expected to complete the pilot study, redefine the project based on pilot study, decide on the appropriate research design, generate data/collect data, develop the algorithm and code, and obtain preliminary results in the third semester. There shall be evaluations of the project work during and at the end of the third semester by a committee constituted by the department.

ME7396E PROJECT PHASE IV

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L	T	P	O	C
0	0	0	45	15

Course Outcomes:

CO1: Analyze and Identify a suitable research methodology for solving the problem identified.
CO2: Apply the methods/tools learned to develop algorithms and solve the problem.
CO3: Analyze and interpret the results using tables and figures for visualization
CO4: Compile and construct a report by employing the techniques of academic writing critical analysis, and defend the thesis
CO5: Publish the findings in reputed journals, conferences or apply for patents

The project work will be extended to the end of the fourth semester. There shall be evaluations of the project work by a committee constituted by the department during the fourth semester. The student shall submit the thesis based on the recommendation of the departmental evaluation committee. There shall be viva-voce examination conducted by an evaluationcommittee with an external examiner.

"The project work/thesis will be considered for awarding Grade 'S' only if a paper, based on whether the project work is published/accepted for presentation at least in a Scopus indexed conference or a software copyright is granted. However, in exceptional cases, where the student and the guide want to submit a journal/conference publication at a later stage and if the student is able to submit the draft version of the journal/conference paper to the evaluation committee at the time of final presentation of the project work, the student may be considered for awarding 'S' grade if the committee finds the work to be excellent and guide ensures the submission of the work for journal/conference publication"

Programme Specific Electives

ME6321E DESIGN OF MECHATRONICS SYSTEMS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Explain various key elements or subsystems in mechatronics.
CO2: Develop PLC programming for automated systems and analyze control part.
CO3: Identify sensors, actuators and data acquisition systems for a given mechatronics system.
CO4: Analyze the requirements and advanced technologies of various subsystems in mechatronics system design through examples

Introduction to mechatronics: key elements in mechatronics, design process, types of design: traditional and mechatronics designs; advanced approaches in mechatronics; real time interfacing; elements of data acquisition system; case studies of mechatronics systems, identification of key elements of various mechatronics systems, examples.

Introduction to signals, system and controls; system representation, linearisation, time delays, measures of system performance; closed loop controller: PID controller, digital controllers, controller tuning, adaptive control; introduction to microprocessors, micro-controllers and programmable logic controllers components, PLC programming, examples.

Actuator and Sensors: fluid power and electrical actuators, piezoelectric actuator; sensors for position,motion, force and temperature, flow sensors-range sensors, ultrasonic sensors, fibre optic sensors, magnetostrictive transducer, selection of sensors; case studies on selection of actuators and sensors for mechatronics systems.
Advanced applications in mechatronics: sensors for condition monitoring, mechatronics control in automated manufacturing; artificial intelligence in mechatronics: fuzzy logic application in mechatronics, case studies and design of mechatronics systems.

References:
[1] Shetty, Devadas., Kolk, Richard A., 2015, *Mechatronics System Design*, Thomson Learning, USA.
[2] Bolton, William, 2019, *Mechatronics: Electronic Control Systems in Mechanical and Electrical engineering*, Pearson education Asia.
[3] Necsulescu, Dan, 2002, *Mechatronics*, Parson Education Asia.
[4] Bishop, Robert H., 2005, *Mechatronics: An Introduction*, CRC Press, USA.
[5] HMT Ltd, 2000, *Mechatronics*, Tata McGraw Hill, India.
[6] Singh, B.P., 2004, *Microprocessors and Microcontrollers*, Galgotia Pub., India.
[7] Petruzella, Frank D., 2010, *Programmable Logic Controllers*, Tata McGraw Hill, India.
[8] Kant, Krishna, 2010, *Computer Based Industrial Control*, PHI, India.
[9] Merzouki, R., Samantaray, A.K., Pathak, P.M., Bouamama, B. Ould, 2013, *Intelligent Mechatronic Systems: Modeling, Control and Diagnosis*, Springer, London.

ME6322E SIX SIGMA WITH DESIGN OF EXPERIMENTS

Prerequisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Explain the basic concepts of the Six Sigma methodology and apply the simple QC tools.
CO2: Analyze data graphically and carry out hypothesis tests.
CO3: Plan and analyze factorial experiments
CO4: Use additional tools and software for analysis of experiments.
CO5: Compute the various metrics used in Six Sigma organizations.

Fundamentals
Introduction – origins, goal, DMAIC strategy, green and black belts – comparison with TQM, tools for six sigma – flowchart, checksheet, histogram, pareto analysis, cause and effect diagram, scatter diagram, control charts

Review of Statistics
Graphical tools: dot plot, box plot, histograms – normal distribution, central limit theorem, chi-square and F distribution, normal probability plotting - hypothesis testing: fundamentals, comparing sample with population, comparing two samples, paired tests, ANOVA.

Planning Experiments
Factorial experiments: terminology, effects and interactions, generating designs, Yates algorithm, testing significance of replicated factorials, developing models, residual analysis, number of replicates, judging significance in unreplicated factorials

Additional tools
Additional tools: testing for curvature, blocking, split plot experiments, response transformations, fractional factorial experiments, alias structure
Planning and execution of a project: student to carry out and present results following DMAIC approach using DoE software

Other topics
Concept of control – funnel experiment and implications for management.
Six sigma metrics : DPO, DPMO, defining opportunities, yield, throughput yield, normalized yield – process capability indices: Cp, Cpk, Cpm, Cpkm, confidence intervals, nonnormal variables– measurement system analysis.
Design for six sigma – case-studies

References:
[1] Breyfogle, F., 1999, *Implementing Six Sigma: Smarter Solutions Using Statistical Methods*, John Wiley & Sons, New York.
[2] Harry, M., and Schroeder, R., 2000, *Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations*, Doubleday, New York.
[3] Lawson, J. and Erjavec, J., 2000, *Modern Statistics for Engineering and Quality Improvement*, Thomson Duxbury, USA.
[4] Montgomery, D. C., 2017, *Introduction to Statistical Quality Control*, John Wiley & Sons, Inc., New York.

ME6323E ADDITIVE MANUFACTURING TECHNOLOGIES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Explain different additive manufacturing systems and processes based on their capabilities and limitations for processing polymers, metals, ceramics and other engineering materials

CO2: Apply strategies to improve the AM part quality by software modifications based on the knowledge about 3-D file structures and digital work flow of additive manufacturing

CO3: Derive analytical/mechanistic models related to various additive manufacturing phenomenon and use them to predict required AM process responses.

CO4: Compare and contrast additive manufacturing processes with conventional manufacturing methods in terms of rate, quality, flexibility, part complexity and cost

CO5: Critically evaluate the emerging applications of AM across major industries, including medical, dental, aerospace, vehicle structures, and consumer products and gain hands on experience in designing and fabricating AM parts.

Principles of Additive Manufacturing (AM)

Introduction, ISO/ASTM definition, generic AM process steps, characteristics of additive manufacturing AM and conventional manufacturing processes, hierarchical structure of AM technologies and product development, AM process classification methods- ISO/ASTM classification of AM processes and standard definitions, AM production economics.

3-D data files for AM and digital work flow

3-D data digital forms and formats, scanning and digitization, generation of 3D data for AM using CAD and other routes, functions of AM software, digital work flow, tessellation and tessellation parameters, chordal error, stair step effects, adaptive slicing , STL formats and limitations, algorithms for error corrections, , characteristics of various 3-D data file for AM, file editing, AMF and 3MF files, texture and color mapping, slicing algorithms, build file, layer data and machine data, process planning, part orientation and support generation.

Additive Manufacturing Processes I

Material extrusion (MEX), material loading, solidification, bonding, support generation, machine types and materials, bio extrusion, direct ink writing, large area material extrusion, powder bed fusion (PBF), process variants and commercial machines, materials and primary binding mechanisms, process parameters, applied energy correlations and scan strategies, process map for track types, DSC curve for polymer laser sintering, metal PBF, analytical modelling, melt pool analyses, solidification behavior, residual stress, porosity and cracks, microstructure and texture, mechanical properties, fatigue performance, post processing, laser and electron beam based PBF system capabilities and limitations, directed energy deposition (DED), powder and wire feeding, Source of energy for DED processes, commercial DED machines and systems, materials and microstructure, melt pool characteristics, post-process for DED, capabilities and limitations of DED, field assisted AM.

Additive Manufacturing Processes II

Vat photo polymerization (VPP), material characteristics, reaction mechanisms, photopolymerization process modeling, vector scan and mask projection VPP technologies, stereolithography apparatus (SLA), Digital light processing (DLP), continuous liquid interface production, binder jetting (BJ) process, printability of the fluids, print heads and printing mechanism, commercial BJ systems, materials, multijet fusion, material jetting, droplet formation, printing indicator, materials and machine systems for MJ, cold spray AM, sheet lamination process, ultrasonic AM, microstructures and mechanical properties, hybrid additive manufacturing, modelling and simulation of AM processes.

Design aspects and applications of Additive Manufacturing

Medical modeling, reverse engineering, architectural modeling and construction, automotive, aerospace energy and other emerging applications of AM, testing and certification of AM parts as per ASTM/ISO standards, test artifacts and benchmarking, tolerance and finish of AM parts, guidelines for AM process selection, design for additive manufacturing, ISO/ASTM design requirement and recommendations, topology optimization, generative design, 4D printing, hands on experience in designing and fabricating AM parts.

References:

[1] Gibson I., Rosen.D.., Stucker B., Khorasani M., 2021, *Additive Manufacturing Technologies*, Springer Nature, Switzerland.

[2] Kai Chua, C., Fai Leong K., 2019, *3D Printing and Additive Manufacturing: Principles and Applications*, World Scientific, Singapore

[3] Ehsan T, Dyuti S., Obehi, O., Liravi I.F., Russo,P., Taherkhani.K, 2022, *Metal Additive Manufacturing*, 2022 John Wiley and Sons , USA.

[4] Patri. K. V., and W. Ma, 2004, *Rapid Prototyping: Laser-based and Other Technologies*, Springer, New York.

[5] Kun Zhou, 2023, *Additive Manufacturing: Materials, Functionalities and Applications*, Springer Nature, Switzerland.

[6] Chee K.C., Wong C., H., Yeong W.,2017, *Standards, Quality Control, and Measurement Sciences in 3D Printing and Additive Manufacturing*, Academic Press, Netherlands.

[7] Olaf D., Axel N, Damien M., ,2019, *A Practical Guide to Design for Additive Manufacturing*, Springer Nature, Switzerland.

[8] Kun Zhou, 2023, *Additive Manufacturing Technology: Design, Optimization, and Modeling*, Wiley-VCH, Germany.

ME6324E INDUSTRIAL MACHINE VISION

Prerequisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Select suitable equipment for image acquisition, and illumination.
CO2: Identify appropriate techniques for Preprocessing
CO3: Use appropriate techniques for Segmentation.
CO4: Apply algorithms for pattern classification.
CO5: Implement image processing techniques for measurement and recognition.

Fundamentals
Introduction: types of inspection tasks, structure of image processing systems, examples.
Image acquisition and illumination: solid state sensors, standard video cameras, other cameras, transmission to computer, optics, lighting.
Image preprocessing: gray scale transformations, image arithmetic, linear filters, other filters.
Positioning: positioning of individual object, orientation of individual object, robot positioning.

Segmentation and Identification
Segmentation: regions of interest, thresholding, contour tracing, edge based methods, template matching.
Mark identification: bar code identification, character identification, identifying pin marked digits on metal, print quality inspection.
Classification: as function approximation, instance-based classifiers, function based classifiers, neural network classifiers.

Recognition and Measurement
Presence verification: simple presence verification, simple gauging for assembly verification, presence verification using classifiers.
Object features: basic features, shape descriptors, gray level features.
Dimension checking: simple gauging, shape checking on punched parts, injection molded parts, high accuracy gauging of threads, calibration.

References:
[1] Demant, C., Streicher-Abel, B., and Garnica, C., 2013, *Industrial Image Processing*, Springer-Heidelburg, New York.
[2] Gonzalez, et al., 2017, *Digital Image Processing Using MATLAB*, McGraw Hill Education, USA.
[3] Gonzalez & Woods, 2017, *Digital Image Processing*, Pearson, USA.
[4] Davies, E.R., 2017, *Computer Vision: Principles, Algorithms, Applications, Learning*, Elsevier, Netherlands.

ME6325E MICRO AND NANO MANUFACTURING PROCESSES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Understand the principles of various micro and nano manufacturing processes.
CO2: Evaluate tools and methods used in micro and nano manufacturing.
CO3: Select suitable manufacturing processes for fabrication of micro and nano features and devices.
CO4: Evaluate various metrology and characterization methods for micro and nano manufacturing processes.

Introduction to micro and nano manufacturing, applications. Scaling laws – types of scaling. Salient features of micro-machining and challenges in nano-, micro-, and meso- scale machining. Overview of micro-fabrication methods – chemical vapor deposition (CVD) – basic principles of CVD, LPCVD, PECVD; physical vapor deposition (PVD) – thermal evaporation and sputtering; lithography – optical and electron beam lithography; dry and wet etching.

Conventional micro-machining processes – micro turning, micro drilling, micro milling, micro grinding, diamond turn machining. Cutting force, surface roughness, chip formation, burr formation. Advanced micro-machining processes – micro electro-discharge machining – principle, system development, heat affected zone, applications; electro-chemical micro-machining – principle, types, applications; laser machining processes – types of lasers for micro-machining, laser micro-machining system; focused ion-beam micro-machining, ultrasonic micro-machining. Nano finishing – magneto-rheological finishing, abrasive flow finishing, and allied finishing processes.

Inspection and metrology; various inspection and metrology based on optical, mechanical, charged beam and electrical. 3D optical profilometer – white light interferometry, focus variation methods. Nano indentation, SEM, TEM, AFM. Force, vibration and acoustic emission measurements.

References:

[1] Jain, V. K., 2012, *Micromanufacturing Processes*, CRC press, USA.
[2] Cheng, K., and Huo. D., 2013, *Micro-Cutting: Fundamentals and Applications*, John Wiley & Sons, Inc, USA.
[3] Jackson, M. J, 2005, *Microfacbrication & Nanomanufacturing*, CRC Press, USA.
[4] Mahalik, N. P., 2010, *Micromanufacturing & Nanotechnology*, Springer, Germany.
[5] McGeough, J. A., 2001, *Micromachining of Engineering Materials*, CRC Press, USA.
[6] Madou, M. J., 2002, *Fundamentals of Microfabrication*, CRC Press, USA.
[7] Cambell, S. A., 2001, *The Science and Engineering of Microelectronic Fabrication*, Oxford University Press, UK.
[8] Das, M., Jain, V. K., and Ghoshdastidar, P. S., 2012, *Nanofinishing Process using Magnetorheological Polishing Medium*, Lambert Academic Publishing, UK.
[9] Leach, R., 2011, *Optical Measurement of Surface Topography*, Springer-Verlag Berlin Heidelberg.
[10] Goodhew, P. J., Humphreys, J., and Beanland, R., 2000, *Electron Microscopy and Analysis*, CRC Press, USA.

ME6326E ADVANCED FLUID POWER CONTROL AND AUTOMATION

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Describe and calculate the efficiency of hydraulic and pneumatic systems with various pump and motors.
CO2: Explain various actuators like DCV, flow control valve, check valve, solenoid valve, push button for hydraulic and pneumatic systems.
CO3: Identify the various ISO symbols for simple circuit design for both hydraulic and pneumatic systems.
CO4: Design hydraulic and pneumatic circuits for various industry applications.

Introduction to hydraulics and pneumatics: their advantages, limitations and applications, ISO symbols and standards in hydraulics, recent developments, applications; basic types and constructions of hydraulic pumps and motors: performance curves and parameters; hydraulic actuators; hydraulic control elements; direction, pressure and flow control valves: valve configurations, general valve analysis, series and parallel pressure compensation; flow control valves;

Electro-hydraulic servo valves-specifications; selection and use of servo valves, Electro hydraulic servomechanisms: electro hydraulic position control servos and velocity control servos; basic configurations of hydraulic power supplies; bypass regulated and stroke regulated hydraulic power supplies; design and analysis of typical hydraulic circuits: use of displacement-time and travels-step diagrams; synchronization circuits and accumulator sizing; meter-in, meter - out and bleed-off circuits; fail safe and counter balancing circuits; Case study of hydraulic circuits for machine tool design; study of hydraulic fluid sim software.

Components of pneumatic systems: direction, flow and pressure control valves in pneumatic systems; development of single and multiple actuator circuits; ISO symbols and standards in pneumatics, safety circuits; valves for logic functions: time delay valve, exhaust and supply air throttling; examples of typical circuits using displacement-time and travel-step diagrams; cascade method; Karnaugh-Veitech mapping method; will-dependent control; travel-dependent control and time dependent control; combined control; program logic control (PLC); electro-pneumatic control and air hydraulic control; applications in assembly, feeding, metalworking, materials handling equipment; Case study of pneumatic machine tool design and industrial automation; study of solid modelling and animation by CATIA software for machine tool design. Internet of things (IOT) for fluid power control automation.

References:

[1] Esposito, A., 2008, *Fluid Power with applications*, Pearson, USA
[2] Johnson, J.L., 2001, *Introduction to Fluid Power*, Delmar Cengage Learning, USA.
[3] Joji, P., 2008, *Pneumatic Controls*, Wiley, India.
[4] Morse, A.C., 1963, *Electro hydraulic Servomechanism*, McGraw-Hill, New York.
[5] Pippenger, J.J., and Koff, R.M., 1959, *Fluid Power Control systems*, McGraw-Hill, New York.
[6] Fitch, E.C., 1966, *Fluid Power Control Systems*, McGraw-Hill, New York.
[7] Khaimovich, E.M., 1965, *Hydraulic Control of Machine Tools,* Pergamon, UK.
[8] Watton, J., 1989, *Fluid Power Systems: Modeling, Simulation and Microcomputer Control*, Prentice Hall, USA.
[9] Merritt, H.E., 1991, *Hydraulic control systems*, Wiley, USA.
[10] Hasebrink, J.P., and Kobler, R., 1975, *Fundamentals of Pnuematics/Electropeumatics*, FESTO.

ME6327E QUALITY ENGINEERING AND MANAGEMENT

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyse the link between quality and cost and assess the impact of quality costs on an organization
CO2: Design and interpret control charts for variables and attributes for controlling and improving the quality of products, processes and services
CO3: Design different acceptance sampling plans and analyse the risks related to quality aspects while using them
CO4: Select and use the relevant quality and reliability tools for controlling and improving the dimensions of quality for products and services
CO5: Use software-based quality tools for the preparation of control charts, designing acceptance sampling plans and performing reliability test data analyses

Principles of Quality Management
Introduction, definitions of quality and related terms as per ASQ and ISO, dimensions of quality, tools for quality planning, quality control and quality assurance, quality costs and their categorifies, relationship between quality and quality costs, case studies of external failure costs, quality and engineering design process, quality function deployment (QFD), quality loss function, product control model and process control model for quality

Process Control and improvement
Process variation and sources, use of control charts, statistical basis of the control charts, derivation and choice of control limits, construction and interpretation of control charts for variables and attributes, rational sub groups, control chart sensitivity, OC curve, average run length, phase I and phase II control chart application, exponentially weighted moving average and the cumulative sum control charts

Acceptance Sampling
The acceptance-sampling problem, lot formation and sampling, guidelines for using acceptance sampling, type a and type b oc curve, binomial nomograph, rectifying inspection, average outgoing
Quality limit (AOQL), average total inspection, double, multiple, and sequential sampling, ASN curve, sampling systems, MIL STD 105E, switching rules, Dodge–Romig plans.

Industry Practices related to Quality
Quality standards, process capability analyses and matrices, six sigma approach, ISO/TS 16949 Automotive industry action group (AIAG) manuals, measurement system analyses, advanced product quality planning (APQP), production part approval process (PPAP), failure mode and effect analyses (FMEA), risk priority number.

Reliability Engineering
Introduction to reliability, reliability matrices, hazard rate function, system reliability, reliability testing, statistical distributions in reliability analysis, types of failure time, fitting models, warranty analyses.

References:
[1] Montgomery D.C., 2019, *Introduction to Statistical Quality Control*, John Wiley and Sons, USA
[2] Mitra A., 2021, *Fundamentals of Quality Control and Improvement*, John Wiley and Sons, USA
[3] Krishnamoorthi K., S., Pennathur, A, Krishnamoorthi. V., 2019, *A First Course in Quality Engineering*, CRC Press, Boca Raton.
[4] Richard E. D., Sutherland J. W.,Chang T., 2007, *Statistical Quality Design and Control: Contemporary Concepts and Methods* , Pearson, USA.
[5] Edward G. S., Dean V. N.,2017, *Acceptance Sampling in Quality Control*, CRC Press, Boca Raton.
[6] Automotive Industry Action Group (AIAG), 2010, *Measurement Systems Analysis Reference Manual*.
[7] Elsayed E. A., 2020, *Reliability Engineering*, John Wiley and Sons, USA.
[8] Pochampally, K. S., Gupta S. M., 2021, *Reliability Analysis with Minitab*, CRC Press, Boca Raton.

ME6328E DESIGN FOR MANUFACTURE AND ASSEMBLY

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Introduction: Philosophy of DFM, implementing DFM, benefits; concurrent engineering: design for quality, design for life cycle, design for cost, enabling technology, concurrent engineering and the organization, improving the development process; management frameworks: architecture, management's concerns with manufacturability, team building and training; justification of DFM, viewpoints for DFM
quality tools in DFM: problem solving tools, quality function deployment, benchmarking, supplier involvement.

Taguchi approach; computer aided technology: CAD/CAM/CAE, rapid prototyping, group technology, CIM; creative thinking in DFM, tools; general product design: impact of design concept and early project decisions, evaluating manufacturability of conceptual designs, producibility, geometric tolerancing.
Design for assembly: principles, improving serviceability, recyclability; design for machining: principles, nontraditional machining; design for forming: principles, fine blanking, roll forming, precision forming, metal spinning, tube fabrication.

Design for forging, casting; design for coating: painting, powder coating, metal spraying; design forheat treatment; design for fastening & joining: design guidelines for fasteners, adhesive assembly,welded assemblies; design for materials: plastics, composites, ceramics, powder metallurgy.

References:

[1] Boothroyd, G., Dewhurst, P., and Knight, W., 2011, *Product Design for Manufacture and Assembly*, Marcel Dekker Inc., USA.
[2] Dieter, G.E., 2012, *Engineering Design - A Materials and Processing approach*, McGraw Hill Education, USA.
[3] Bakerjian, R., 1992, *Design for Manufacturability*, *Tool and Manufacturing Engineers Handbook*, Society of Manufacturing Engineers, Michigan.
[4] Anderson, David M., 2014, *Design for Manufacturability*, CRC Press, USA.
[5] Bralla, James G., 1998, *Design for Manufacturability Handbook,* McGraw Hill, USA.

ME6329E DESIGN FOR X

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Learn a systematic procedure to analyze a proposed design from the point of view of assembly and manufacturing.
CO2: Identify design constraints and choose suitable guidelines for the different processes.
CO3: Quantitatively evaluate the impact of design choices on manufacturing and get familiar with key concepts in various new manufacturing paradigms.
CO4: Use modern software tools to accurately model parts for specific manufacturing processes, simplify and benchmark products and quantify improvement and environmental impact.

Design for Manufacturing and Assembly (DFMA)
Introduction to DFMA, selection of materials and processes product design for manual assembly design for injection moulding design for sheetmetal working, design for die-casting, sand casting, and investment casting, design for machining.

Design for Environment (DFE)
Introduction to sustainability and sustainable design, product life cycle design- methods and strategies, design for human factors; design for X – reliability, serviceability, environment, disassembly, ISO standards, eco audit tools, introduction to PLM and LCA software.

Design for Additive Manufacturing (DFAM)
Introduction to design for additive manufacturing (DfAM), design guidelines for part consolidation, design for improved functionality, design for polymer AM, design for metal AM, computational tools for design analysis, considerations for analysis of AM parts, material data, surface finish, geometry.

References:

[1] Boothroyd, G., Dewhurst, P., and Knight, W., 2011, *Product Design for Manufacture and Assembly*, Marcel Dekker Inc., USA.
[2] Fiksel, Joseph, *Design for Environment*: *A Guide to Sustainable Product Development*, McGraw-Hill Professional, USA.
[3] Olaf, Axel Nordin, and Damien, Motte, 2020, *A Practical Guide to Design for Additive Manufacturing*, Springer, Switzerland.
[4] Redwood, Ben, Filemon Schoffer, and Brian Garret, 2017, *The 3D Printing Handbook: Technologies, Design and Applications*, 3D Hubs., Netherlands.

ME6330E ADVANCED JOINING TECHNOLOGIES

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Explain the principles and process characteristics of various advanced joining processes.
CO2: Explain the dependence of process parameters and the evolution of material properties in joining
CO3: Optimize and design weld joint/equipment/tools/process parameters in welding
CO4: Describe the evolution of defects, its metallurgical aspects and inspection methods for the quality assurance in welding

Elements of weld setup, classification of welding processes, microstructural zones in welding, concept of continuity in welding, gas welding, arc welding; arc physics, concepts, processes and applications of manual metal arc welding, gas metal arc welding, gas tungsten arc welding, welding electrodes, power source characteristics, polarity, modes of metal transfer, CO_2 welding, submerged arc welding, electro slag and electro gas welding, plasma welding, resistance welding, under water welding.

Friction welding: Concepts, types and applications; Friction stir welding: Metal flow phenomena, tools, process variables and application. Explosive, diffusion and ultrasonic welding: principles of operation, process characteristics and applications. EBW: concepts types and applications. LBW: physics of lasers, types of lasers, operation of laser welding setup, advantages and limitations, applications. Soldering: techniques of soldering, solders, phase diagram, composition, applications; brazing: wetting and spreading characteristics, surface tension and contact angle concepts, brazing fillers, role of flux and characteristics, atmospheres for brazing; adhesive bonding; cladding.

Heat flow, temperature distribution, cooling rates, influence of heat input; joint geometry, plate thickness, preheat, significance of thermal severity number. Epitaxial growth, weld metal solidification, columnar structures and growth morphology, effect of welding parameters; absorption of gases, gas/metal and slag/metal reactions. Phase transformations, weld CCT diagrams, carbon equivalent-preheating and post heating. Weldability of steels: low alloy steels, stainless steels use of Schaffler and Delong diagrams; welding of cast irons. Welding of Cu, Al, Ti and Ni alloys: processes, difficulties, microstructures, defects and remedial measures. Process induced defects: significance, remedial measures, hot cracking, cold cracking, lamellar tearing, reheat cracking. Weldability tests, effect of metallurgical parameters. Weld testing and characterization, computational study through software packages.

References:
[1] Parmer, R.S., 1997, *Welding Engineering and Technology*, Khanna Publishers, India.
[2] Howard, B. Cary, 1998, *Modern Welding Technology*, Prentice Hall, USA.
[3] Linnert, G.E., 1994, *Welding Metallurgy*, Vol. I and II, AWS, USA.
[4] Granjon, H., 1994, *Fundamentals of Welding Metallurgy*, Jaico Publishing House, India.
[5] Kenneth Easterling, 1992, *Introduction to Physical Metallurgy of Welding*, Butterworth Heinmann Ltd., UK.
[6] Saferian, D., 1985, *The Metallurgy of Welding*, Chapman and Hall, UK.
[7] Mishra, R.S., and Mahoney, M.W., 2007, *Friction Stir Welding and Processing*, ASM, USA.
[8] Kou Sindo, 2002, *Welding Metallurgy*, Wiley, USA.
[9] Nadkarni, S.V., 1996, *Modern Arc Welding Technology*, Oxford IBH Publishers, India.
[10] Christopher Davis, 1994, *Laser Welding - A Practical Guide*, Jaico Publishing House, India.
[11] Messler, Robert W., 2004, *Principles of Welding*, WILEY-VCH Verlag, Germany.
[12] Lancaster, J.F., 1999, *Metallurgy of Welding*, Abington, Cambridge: Abington Pub., UK.
[13] Little, A. Richard, 2017, *Welding and Welding Technology*, Tata McGraw Hill, India.

ME6331E METAL ADDITIVE MANUFACTURING: TECHNOLOGIES AND PRACTICE

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:

CO1: Understand the fundamental principles and concepts of metal additive manufacturing (AM) technologies compared to traditional manufacturing methods.
CO2: Identify and evaluate the material and metallurgical aspects of different metal AM technologies for various critical and non-critical components
CO3: Apply modelling and simulation principles to metal AM to optimize the manufacturability and performance of metal parts.
CO4: Evaluate the process-structure-property relationship of metal AM parts using testing and characterization techniques.
CO5: Apply knowledge of safety protocols and ASTM/ISO standards in working with metal AM equipment and feed stock materials.
CO6: Analyse case studies and real-world applications of metal AM in industries such as aerospace, automotive, healthcare, and more.

Introduction to metal additive manufacturing (MAM): overview of metal additive manufacturing, brief history of metal additive manufacturing, advantages and limitations of metal additive manufacturing, comparison with traditional manufacturing methods, applications of MAM (medical, aerospace, automotive, moulds and tooling, remanufacture and repair, scanning and reverse engineering, engineered structures, functionally graded structures, etc., hybrid additive/subtractive systems, process steps.

Material aspects in MAM process: overview of metal powders; powder production: elemental and pre-alloyed metal powders, atomization process, reduction of compounds, electrolysis, additives; physical, chemical and microstructural characterization of powders; powder handling, storage, reuse and cleanliness. Physics of energy-material interaction: influence of lasers, electron beams and plasma arcs on microstructure and properties. Metallurgical aspects of MAM process: solidification, diffusion, phase transformation, surface energy, sintering, texture, non-equilibrium microstructure, residual stress; process-structure-property relationship, design of tailored structure for end application. Reuse of powder and their effects on properties and part performance.

MAM technologies: laser powder bed fusion, laser direct energy deposition, additive manufacturing with electron beams, metal printing with arc welding systems , binder jetting technology, solid state additive manufacturing technologies, ultrasonic consolidation, cold spray technology, nano and micro scale methods, other MAM technologies; mathematical models for additive manufacturing: transport phenomena models: temperature, fluid flow, and composition, buoyancy driven, tension driven free surface flow, case studies: numerical modelling of AM processes: powder bed fusion, droplet based, residual stress, optimal orientation, defects prediction, simulations for selection of parameters; post processing and inspection: support removal, defects and defect criticality, heat treatment, surface finishing, hot isostatic pressing, shot peening, influence of post processing on the mechanical properties of AM components, non-destructive testing, quality control techniques.

MAM standards and qualification: introduction to additive manufacturing standards, need for standards, standardization process. Fundamentals of qualification and certification - purpose, principles and applications, how AM qualification differs from conventional qualification process, quality management system for AM, creating a frame work of metal AM qualification – material, machine, process, personnel, and part qualification, using standards to develop qualification framework, use cases with published AM international standards, future of AM qualification – model based rapid qualification; applications of MAM: aerospace and defense, medical and dental, automotive and transportation, jewelry and fashion, future trends and challenges.

References:

[1] Gibson Ian, Rosen David, Stucker Brent, and Khorasani Mahyar, 2021, *Additive Manufacturing Technologies*, Springer, Switzerland.
[2] Milewski, John O., 2017, *Additive Manufacturing of Metals*, Springer, Switzerland.
[3] Hosford, William F, 2007, *Material Science: an intermediate text*, Cambridge, UK.
[4] Bourell, David L., Frazier, William, Kuhn Howard, and Seifi Mohsen, *ASM Handbook, Volume 24: Additive Manufacturing Processes*, USA.
[5] German, R.M., 1994, *Powder Metallurgy Science*, Metal Powder Industry, USA.
[6] ISO/ASTM 52904 *Additive manufacturing — Process characteristics and performance — Practice for metal powder bed fusion process to meet critical applications*.
[7] ISO/ASTM 52930 *Additive manufacturing — Qualification principles — Installation, operation and performance (IQ/OQ/PQ) of PBF-LB equipment.*
[8] ISO/ASTM 52902 *Additive manufacturing — Test artifacts — Geometric capability assessment of additive manufacturing systemsy.*
[9] ISO/ASTM 52907 *Additive manufacturing — Feedstock materials — Methods to characterize metal powders.*

ME6332E MACHINING DYNAMICS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course outcomes:
CO1: Analyze and create dynamics model for turning, milling and grinding.
CO2: Analyze energy equation and chatter in intermittent machining processes
CO3: Analyze controllability of dynamic strategies for machining
CO4: Explain and derive concepts behind chatter controllability

Modelling of machining Processes
Machining process modelling and analyses: Analysis of 2D and 3D machining processes. Static and dynamic loop stiffness, mechanistic modelling of 2D machining processes: processes, geometry, chip morphology, stress, strain, force modelling, 3D oblique cutting mechanics. Modelling of turning and milling processes: tool wear, tool life and cutting economics.

Vibration and Modal analysis
Brief introduction of SDOF and MDOF systems, review of system matrix development. Introduction to modal analysis. Orthogonality properties and damped systems. Modal data acquisition: signal processing, transducer selection and design. Frequency response functions. Modal parameter extraction.

Machining dynamic analysis and chatter
Dynamic model for orthogonal cutting, machining instability and control. Machine tool dynamics. Dynamic cutting forces, stability analysis, single tooth, one-dimensional, linear time invariant models, feedback mechanisms and phase shifts, machining stability of turning. Stability solutions using traditional and frequency domain approaches. Stability of milling processes. High speed machining materials–induced vibration in single point diamond turning

References:
[1] Altintas., Yusuf, 2012, *Manufacturing Automation*, Cambridge University, UK.
[2] Jack H., 2021, *Integration and automation of manufacturing systems*.
[3] Schmitz, T., and Smith, K., 2009, *Machining Dynamics*, Springer, New York.
[4] Koenigsberger, F., and Tlusty, J., 1970, *Machine Tool Structures*, Elsevier, Netherlands.
[5] Cheng, Kai, 2009, *Machining Dynamics*, Springer, United Kingdom.
[6] Sweeney, G., 1971, *Vibration of machine tools*, The Machinery Publishing.
[7] Weck, M., 1980, *Handbook of Machine Tools*, Volume 2 Wiley, London.
[8] Rao, S.S., 2003, *Mechanical Vibrations*, Prentice Hall, New Jersey, USA.
[9] Tobias, S.A., 1965, *Machine Tool Vibration*, Blackie and Son, London.
[10] Armarego, E.J.A., and Brown, R.H., 1969, *The Machining of Metals*, Prentice–Hall, London.
[11] Shaw, M.C., 1986, *Metal Cutting Principles*, Clarendon Press, Oxford, UK.
[12] Stephenson, D.A., and Agapiou, J.S., 1997, *Metal Cutting Theory and Practice*. New York.
[13] Youssef, H., and El-Hofy, H., 2020, *Traditional machining technology*, CRC Press, USA.

ME6333E LASER MATERIAL PROCESSING

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyze, model rate equations for industrial lasers.
CO2: Derive heat transfer and flow models for beam process.
CO3: Analyze various laser beam manufacturing processes.
CO4: Derive and model laser beam machining for additive manufacturing.

Introduction to Lasers: basic principle of laser generation, stimulated emission; properties of laser beam, gain medium, optical resonator, pump source, laser beam delivery systems, introduction and basic fundamentals and characteristics of different industrial lasers: He-Ne, CO_2, Nd: YAG, excimer, fiber, diode and ultra-short pulse lasers, economics of laser application and safety issues.

Laser processing fundamentals: brief introduction to metal additive manufacturing. Laser beam interaction with metal and powder. Heat flow theory; energy balance during processing, heat flow, temperature distribution, detailed mathematical modelling of heat source models, Gaussian, uniform, circular, ellipsoidal, quadruple, double ellipsoid, egg configuration heat source models. Cooling rates, fluid flow in molten pool, free surface modelling, flow parameters modelling. Heat source modelling in COMSOL. Microstructure, zone of partial melting in additive manufacturing. Solidification with flow mushy fluid. Residual stresses and measurement in additive manufactured parts/laser processed parts. Modelling and simulations in laser material processing using commercially available software COMSOL and ANSYS

Laser material processing applications; laser cutting and drilling, the challenges ahead for laser macro, micro and nano manufacturing, laser fusion cutting of difficult materials, laser dicing of silicon and electronics substrates, laser welding: laser microspot welding, laser hybrid welding, pulsed and continuous wave laser welding pulsed laser annealing technology, thick metallic coatings produced by coaxial and side laser cladding, laser micro/nano-fabrication techniques and their applications in electronics, laser-assisted additive fabrication of micro-sized coatings, lasers for additive manufacturing, multiphysics modelling of laser solid freeform fabrication techniques, laser shock peening; laser etching and paint striping; LCVD and LPVD; laser hybrid machining; liquid assisted laser machining.

References:
[1] Silfvast, William T., 2004, *Laser Fundamentals*, Cambridge University Press, UK.
[2] Orazio Svelto, 2010, *Principles of Lasers*, Springer, Switzerland.
[3] Steen, W.M., and Mazumder, J.,2010, *Laser Material Processing*, Springer, Switzerland.
[4] Elijah Kannatey–Asibu, Jr., 2009, *Laser Materials Processing*, Wiley, USA.
[5] Dahotre, Narendra B., 2008, *Laser Fabrication and Machining of Materials*, Springer, Switzerland.
[6] Lawrence, J., 2017, *Advances in Laser Materials Processing*, Woodhead Publishing, USA.
[7] Grigoriev, Sergey N., *Advances in Laser Materials Processing*, MDPI Books, Switzerland.

ME6334E COMPUTATIONAL METROLOGY

Prerequisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Analyze algorithms and determine their computational complexity.
CO2: Apply filters to surface texture data and compute parameters.
CO3: Fit substitute surfaces to coordinate data
CO4: Compute the uncertainty of parameters and features determined using computational methods.

Algorithms
Analysis of algorithms – asymptotic notation – divide and conquer algorithms, the master method, experimental method - programming in MATLAB.

Filtering
Electrical filters – digital filters.
Frequency domain filtering – discrete fourier transform, wrap-around effect, characteristics
Time domain filtering – gaussian filter – the 2 RC filter – filtering 3D surfaces - filtering roundness profiles
Gaussian regression filters – spline filter – robust filters – envelope and morphological filters – multiscale filtering – computation of parameters – autocorrelation, power spectrum density, bearing area

Fitting
Fitting criteria – least squares fit – non-linear least squares – line, plane, circle, sphere, cylinder, freeform surfaces - the Limacon approximation – exchange algorithms – linear programming – other techniques.

Uncertainty
Uncertainty analysis according to the GUM - numerical approaches, Monte Carlo method: overview, generation of random numbers, modelling statistical distributions of variables, analysing output results, uncertainty of substitute geometries, Bayesian approach.

References:

[1] Roughgarden, T., 2017, *Algorithms Illuminated Part 1: The Basics,* Soundlikeyourself Publishing, New York.
[2] Muralikrishnan, B., and Raja, J., 2009, *Computational surface and roundness metrology*, Springer-Verlag, London.
[3] Crowder, S., Delker, C., Forrest, E., and Martein, N., 2020, *Introduction to Statistics in Metrology,* Springer Nature, Switzerland.
[4] Shaw, B. D., 2017, *Uncertainty analysis of experimental data with R,* CRC Press, Boca Raton.
[5] Stevens, A., 2022, *Monte-Carlo Simulation An Introduction for Engineers and Scientists*, CRC Press, Boca Raton.

ME6335E ADDITIVE MANUFACTURING FOR MEDICAL APPLICATIONS

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: **39**

Course Outcomes:
CO1: Apply the concepts of medical imaging, 3D scanning and digitizing for accurate 3D model construction.
CO2: Identify the errors during processing of medical image data and minimize them.
CO3: Select the suitable material for the given medical application.
CO4: Analyze and select an additive manufacturing technology for a given medical application.
CO5: Analyze and design the virtual models of the patient for planning the surgery.

Overview of additive manufacturing technologies, reverse engineering and rapid prototyping, stereolithography and other resin-based systems, fused deposition modelling and selective laser sintering, droplet/binder systems, related technology: microsystems and direct metal systems, file preparation, relationship with other technologies, bioprinting, bioinks.

Introduction to medical imaging, conversion of MRI/CT data to 3D model, importing a DICOM dataset, volume reduction, anatomical orientation confirmation, volume editing, image processing, build orientation optimization, 3D visualization, RP file generation, virtual reality and surgical planning, cranio-maxillofacial biomodelling, vascular biomodelling, skull-base tumour surgery, spinal surgery, orthopaedic biomodelling, case studies.

Medical devices and related AM technologies, laser material processing applications; introduction to orthopaedic implants, electron beam melting technology, direct fabrication of titanium orthopaedic implants - EBM fabrication of custom knee implants, EBM fabrication of custom bone implants, direct fabrication of bone ingrowth surfaces, surface modification and characterization of AM parts, future development of medical applications for advanced manufacturing technology.

References:
[1] Gibson, Ian, 2005, *Advanced Manufacturing Technology for Medical Applications*, John Wiley, USA.
[2] Bartolo, Paulo, and Bidanda, Bopaya, 2008, *Bio-materials and Prototyping Applications in Medicine*, Springer, Switzerland.
[3] Bronzino, Joseph D., 2006, *The Biomedical Engineering Hand Book*, CRC Press, USA.
[4] Paul, C.P, and Junoop, A.N., 2021, *Additive Manufacturing: Principles, Technologies and Applications*, McGrawHill, India.
[5] Rafiq, Noorani, 2006, *Rapid Prototyping: Principles and Applications in Manufacturing*, John Wiley & Sons, USA.
[6] Kai, Chua and Yee, Yeong, 2015, *Bio-Printing: Principles and Applications*, World Scientific Publishing, Singapore.
[7] Bartolo, Paulo and Bopaya, Bidanda, 2008, *Bio-materials and Prototyping Applications in Medicine*, Springer, Switzerland.
[8] Kalaskar, Deepak, 2017, *3D Printing in Medicine*, Woodhead publishing, UK.

ME6336E APPLICATIONS OF LASER IN MANUFACTURING

Prerequisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
CO1: Explain the principles of various laser-based manufacturing processes.
CO2: Analyze the effect of process parameters and the evolution of material properties during laser welding, forming, additive manufacturing and surface treatment.
CO3: Identify the suitable laser for processing materials.
CO4: Analyze the defects and recommend suitable surface modification techniques for quality assurance.

Lasers in manufacturing: importance and application, fundamentals of laser technology, Laser system: construction and types.

Laser cutting: principle of operation, types of laser cutting, and kerf geometry, types of lasers in material removal, process and performance parameters, a case study on cutting a circular part using CO_2 laser machine.
Laser welding: mechanisms of laser welding, effects of process parameters during laser welding and study of defects in weld bead, a case study on welding of mild steel sheets using CO_2 laser machine. Case studies on laser welding of different materials.
Metal forming and fundamentals of laser forming, mechanisms of laser forming, process parameters and their effects on the performance of laser forming. Case studies on laser bending of ductile and brittle materials.
Surface treatment and application of lasers, laser surface hardening, laser surface alloying, laser cladding. Case studies on laser surface treatment of different materials.

Additive manufacturing techniques, laser scanning stereolithography, selective laser sintering and selective laser melting, process and performance parameters of laser based additive manufacturing techniques; Lasers in manufacturing automation, CNC for laser-based manufacturing, CAD for laser-based manufacturing. Case studies on laser based additive manufacturing processes.

Laser assisted metal forming, laser assisted machining, effect of coatings, 3D laser forming and micro-forming. Case studies on laser assisted processes.

References:
[1] Steen, W.M., and Mazumder, J., 2010, *Laser Material Processing*, Springer, Switzerland.
[2] Ready, J.F., and Dave, Farson F., 2001, *LIA Handbook of Laser Materials Processing*, Laser Institutes of America, USA.
[3] Katayama, Seiji, 2013, *Handbook of laser Welding Technologies*, Woodhead Publishing Limited, UK.
[4] Dixit, U.S., Joshi, S.N. and Kant, R., 2015. *Laser forming systems: a review*. International Journal of Mechatronics and Manufacturing Systems, 8(3-4), pp.160-205.
[5] Lawrence, J., 2017, *Advances in Laser Materials Processing*, Woodhead Publishing, UK.
[6] Joshi, S.N., and Dixit, U.S., 2014, *Lasers Based Manufacturing*, Springer, New Delhi.

ME6337E SMART MANUFACTURING TECHNOLOGIES

Pre-requisites: NIL

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:

CO1: Assess the various 3D data files and representations and select the suitable 3D files for various engineering applications.
CO2: Explain the structure and use of STEP files for various interoperability applications.
CO3: Develop digital models for manufacturing elements and propose reference architecture for digital twin modelling.
CO4: Apply the concepts of digital thread and digital twin aiding automation of downstream design and manufacturing applications.

3D data files

Introduction to digital manufacturing technologies for smart factories, digital product design, 3D data digital forms and formats, point clouds, voxels, meshes, surface model-parametric and non-parametric, solid model-boundary representation (B-reps) and constructive solid geometry, mathematical elements of CAD, properties and applications of digital formats, form approaches, parametric modeling, procedural modeling, part digitalization, generative design.

Digital thread

Native and neutral 3D files, structure and properties of IGES, STEP, STL, QIF, 3D PDF, JT, PARASOLID model based definition (MBD), model based engineering systems, model based enterprises, MBD and non MBD files, ISO10303 standards for industrial automation systems and integration, information modelling using EXPRESS, part 21 files, XML files, STEP data access interface, application protocols, STEP AP 209- multidisciplinary analysis and design, AP233-systems engineering STEP AP203 , AP 214, STEP AP242, STEP AP STEP-NC AP238, feature passed process planning using STEP, STEP -NC compliant CNC and manufacturing process optimization, ISO 14649- digital semantic manufacturing modelling, STEP in the context of PDM and PLM, STEP AP 239, STEP in the context of PDM and PLM.

Digital twin and Cyber Physical Production Systems

Digital twin, modelling approaches, service encapsulation of digital twin, ISO 23247, digital representation of manufacturing elements, universally unique identifier, reference architecture, digital twin framework for manufacturing, automation markup language, OPC unified architecture, MT connect, digital twin shop floor, Interaction mechanism in DTS, physical elements fusion, multidimension models fusion, digital twins for prognostics and health management of engineering systems, configuration of cyber physical production systems (CPPS) , real time data from CPPS operation, sensor networks and industrial IoT.

Applications

Applications and case studies of digital twin and digital thread in design and manufacturing, smart factories,
Automation of downstream design and manufacturing applications, fixture planning, CNC programming, tolerance analyses, robotics path planning, QIF based smart metrology and inspection, STEP AP 209 based simulation and analyses, cyber physical machine tools, data driven overall equipment effectiveness (OEE) analyses of smart manufacturing.

References:

[1] Patel D.D., Chen C.H., 2022, *Digital Manufacturing*, Elsevier, Netherlands
[2] Zhang M, Tao F, and Nee A.Y.C., 2019, *Digital Twin Driven Smart Manufacturing*, Academic Press, USA
[3] Xun X., and Nee A.Y.C., 2009, *Advanced Design and Manufacturing Based on STEP*, Springer, Verlag London.
[4] Rogers D.F., and Adams J.A, 2017, *Mathematical Elements for Computer Graphics*, McGraw Hill, New Delhi.
[5] Chaudhery M.H., and Daniel, R., 2023, *Designing Smart Manufacturing Systems*, Academic Press, USA.
[6] Wang L., and Wang X.V., 2018, *Cloud-Based Cyber-Physical Systems in Manufacturing*, Springer Nature, Switzerland
[7] Soroush M., Michael B., and Edgar T.F., 2020, *Smart Manufacturing: Concepts and Methods*, Elsevier, Netherlands.

INSTITUTE ELECTIVES

IE6001E ENTREPRENEURSHIP DEVELOPMENT

Pre-requisites: NIL

L	T	P	O	C
2	0	0	4	2

Total Lecture Sessions: 26

Course Outcomes:

CO1: Describe the various strategies and techniques used in business planning and scaling ventures.
CO2: Apply critical thinking and analytical skills to assess the feasibility and viability of business ideas.
CO3: Evaluate and select appropriate business models, financial strategies, marketing approaches, and operational plans for startup ventures.
CO4: Assess the performance and effectiveness of entrepreneurial strategies and actions through the use of relevant metrics and indicators.

Entrepreneurial Mindset and Opportunity Identification
Introduction to Entrepreneurship Development - Evolution of entrepreneurship, Entrepreneurial mindset, Economic development, Opportunity Recognition and Evaluation - Market gaps - Market potential, Feasibility analysis - Innovation and Creativity in Entrepreneurship - Innovation and entrepreneurship, Creativity techniques, Intellectual property management. .

Business Planning and Execution
Business Model Development and Validation - Effective business models, Value proposition testing, Lean startup methodologies - Financial Management and Funding Strategies - Marketing and Sales Strategies - Market analysis, Marketing strategies, Sales techniques - Operations and Resource Management - Operational planning and management, Supply chain and logistics, Stream wise Case studies.

Growth and Scaling Strategies
Growth Strategies and Expansion - Sustainable growth strategies, Market expansion, Franchising and partnerships - Managing Entrepreneurial Risks and Challenges - Risk identification and mitigation, Crisis management, Ethical considerations - Leadership and Team Development - Stream wise Case studies.

References:

[1] Kaplan, J. M., Warren, A. C., & Murthy V. (Indian Adoption), 2022, *Patterns of entrepreneurship management.* John Wiley & Sons.
[2] Kuratko, D. F., 2016, *Entrepreneurship: Theory, process, and practic*e. Cengage learning.
[3] Barringer, B. R. 2015, *Entrepreneurship: Successfully launching new ventures*. Pearson Education India.
[4] Shah Rajiv, Zhijie Gao, Harini Mittal, 2014, *Innovation, Entrepreneurship, and the Economy in the US, China, and India,* Academic Press.
[5] Sundar, K., 2022, *Entrepreneurship Developmen*t, Vijaya Nichkol Imprints, Chennai.

[6] Gordon, E., Natarajan, K., *Entrepreneurship Development*, Himalya Publishers, Delhi.
[7] Biswas Debasish, Dey Chanchal, 2021, *Enterpreneurship Development in India*, Taylor & Francis.

ZZ6002E RESEARCH METHODOLOGY

Pre-requisites: NIL

L	T	P	O	C
2	0	0	4	2

Total Lecture sessions: 26

Course Outcomes
CO1: Explain the basic concepts and types of research.
CO2: Develop research design and techniques of data analysis
CO3: Present research to the scientific community
CO4**:** Develop an understanding of the ethical dimensions of conducting research

Exploring Research Inquisitiveness
Philosophy of Scientific Research, Role of Research Guide, Planning the Research Project, Research Process, Research Problem Identification and Formulation, Variables, Framework development, Research Design, Types of Research, Sampling, Measurement, Validity and Reliability, Survey, Designing Experiments, Research Proposal, Research Communication, Research Publication, Structuring a research paper, structuring thesis/ dissertation.

Data Analysis
Literature review :Tools and Techniques - Collection and presentation of data, processing and analysis of data - Descriptive statistics and inferential statistics- Measures of central tendency, dispersion, skewness, asymmetry- Probability distributions – Single population and two population hypothesis Testing - Parametric and non-parametric tests - Design and analysis of experiments: Analysis of Variance (ANOVA),completely randomized design – Measures of relationship: Correlation and regression, simple regression analysis, multiple regression – interpretation of results - Heuristics and simulation

Research writing and Ethics
Reporting and presenting research, Paper title and keywords, writing an abstract, writing the different sections of a paper, revising a paper, responding to peer reviews.
The codes of ethics, copyright, patents, intellectual property rights, plagiarism, citation, acknowledgement, avoiding the problems of biased survey

References:
[1] Krishnaswamy, K.N., Sivakumar, A.I., and Mathirajan, M., 2006, *Management Research Methodology, Pearson* Education.
[2] Leedy, P, D., 2018, *Practical Research: Planning and Design*, Pearson.
[3] Kothari, C.R., 2004, *Research Methodology – Methods and Techniques*, New Age International Publishers.
[4] Martin Mike, Schinzinger Roland, 2004, *Ethics in Engineering*, Mc Graw Hill Education.
[5] Sople, Vinod V., 2014, *Managing Intellectual Property-The Strategic Imperative*, EDA Prentice of Hall Pvt. Ltd.

MS6174E TECHNICAL COMMUNICATION AND WRITING

Pre-requisites: NIL

L	T	P	O	C
2	1	0	3	2

Total Lecture Sessions: 26

Course Outcomes:

CO1: Apply effective communication strategies for different professional and industry needs.
CO2: Collaborate on various writing projects for academic and technical purposes.
CO3: Combine attributes of critical thinking for improving technical documentation.
CO4: Adapt technical writing styles to different platforms.

Technical Communication
Process(es) and Types of Speaking and Writing for Professional Purposes - Technical Writing: Introduction, Definition, Scope and Characteristics - Audience Analysis - Conciseness and Coherences - Critical Thinking - Accuracy and Reliability - Ethical Consideration in Writing - Presentation Skills - Professional Grooming - Poster Presentations

Grammar, Punctuation and Stylistics
Constituent Structure of Sentences - Functional Roles of Elements in a Sentence - Thematic Structures and Interpretations - Clarity - Verb Tense and Mood - Active and Passive Structures - Reporting Verbs and Reported Tense - Formatting of Technical Documents - Incorporating Visuals Elements - Proofreading

Technical Documentation
Types of Technical Documents: Reports, Proposals, Cover Letters - Manuals and Instructions - Online Documentation - Product Documentation - Collaborative Writing: Tools and Software - Version Control Document Management - Self Editing, Peer Review and Feedback Processes

References:

[1] Foley, M., and Hall, D., 2018, *Longman advanced learner's grammar, a self*-*study reference & practice book with answers*, Pearson Education Limited.
[2] Gerson, S. J., and Gerson, S. M., 2009, *Technical writing: Process and product*, Pearson.
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