Mechatronics engineering syllabus

Mechatronics engineering examinations

Group A - Compulsory examinations (seven required)

23-Mechatronics-A1 - Systems Dynamics and Controls

Open-loop and feedback control. Mathematical models of mechanical, hydraulic, pneumatic, electrical devices. Block diagrams, transfer functions, response of systems to typical input signals (step function, impulse, harmonic), frequency response, Bode diagram, stability analysis, and stability criteria. Regulation of physical processes: proportional, integral, and derivative control. Theory of linear state-space controller design.

Textbooks (most recent edition is recommended):

- Nise, N., S., Control Systems Engineering, Wiley
- Golnaraghi, F., Kuo, B., Automatic Control Systems, McGraw Hill
- Ogata, K., Modern Control Engineering, Pearson.

23-Mechatronics-A2 - Circuits and Electronics

Nodal and mesh analysis of linear passive circuits: Kirchoff's Laws, Thevenin and Norton equivalent circuits, maximum power transfer theorem.

Semiconductor physics, p-n junction, diode circuits and applications. Transistors: Bipolar Junction Transistor (BJT) and Field Effect Transistor (FET). Transistors as linear devices and switches. Amplifier types and classes: bias circuits, small-signal equivalent circuits. Pulse-width modulation (PWM) control: conduction and switching losses in transistors. Operational amplifiers (op-amps): applications in analog signal conditioning for instrumentation and control. DAC and ADC. Op-amp comparators. Digital integrated circuits and logic families: TTL and CMOS.

Textbooks (most recent edition is recommended):

- Nilsson, James W. and Susan Riedel, Electric Circuits, Prentice Hall.
- Schwarz and Oldham, Electrical Engineering: An Introduction, Oxford University Press.
- Sedra and Smith, Microelectronic Circuits, Oxford University Press.

23-Mechatronics-A3 - Digital Logic and Embedded Systems

Number systems and logic gates. Combinational logic design: Boolean algebra, truth tables, minterms, maxterms, Karnaugh maps; gates, buffers, multiplexers and decoders; combinational circuit timing. Sequential logic design: latches and D flip flops; timing considerations; analysis and synthesis techniques; counters and registers. Programmable Logic Controllers (PLCs) and PLC programming using IEC 61131-3. Microcontroller structure, operation, and programming: I/O, and interfacing with peripherals (e.g., ADC/DAC, PWM).

Textbooks (most recent edition is recommended):

- Sedra, Adel S., Kenneth C. Smith, Tony Chan Carusone, and Vincent Gaudet, Microelectronic Circuits, Oxford University Press.
- Bolton, William, Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering, Pearson.

23-Mechatronics-A4 - Data Structures and Algorithms

Fundamental structures and algorithms for storing, managing, manipulating and analyzing data. Structures, such as multidimensional arrays, linked lists, stacks, queues, asymptotic notation, hash and scatter tables, trees and search trees, heaps and priority queues, graphs, and algorithms such as recursion, branch-and-bound methods, searching, sorting, and probabilistic algorithms.

Textbooks (most recent edition is recommended):

- Standish, Data Structures, Algorithms, and Software Principles in C, Pearson.
- Weiss, Data Structures and Algorithm Analysis in C++, Pearson.

23-Mechatronics-A5 - Mechanical Design

Stress strain in solids, superposition, energy theorems, theories of failure, elastic and inelastic analysis of symmetrical bending, torsion of circular members, and virtual work. Adequacy assessment and synthesis of machine elements with a focus on the design process. Static failure of ductile and brittle materials, fatigue analysis of structures. Topics include the design of welds, bolted connections, bearings, and shafts. Solution strategies include both analytical and finite element methods.

Interweaves mechanisms, electronics, sensors, and control strategies with software and information technology to examine the demands and ideas of customers and find the most efficient, cost-effective method to transform their goals into successful commercial products.

Textbooks (most recent edition is recommended):

- Norton, Robert L., Machine Design: An Integrated Approach, Pearson.
- Budynas, R., K. N. Nisbett, Shigley's Mechanical Engineering Design, McGraw-Hill.

23-Mechatronics-A6 - Kinematics and Dynamics of Machines

Planar kinematics and kinetics of rigid bodies and mechanisms; linkages, gears; synthesis and analysis of mechanisms; consideration of the static and dynamic forces in machines; vibration analysis, response to shock, motion and force transmissibility, vibration isolation.

Vibration Analysis includes free and forced vibration of undamped and damped lumped single and multi-degrees of freedom systems with analytical and numerical techniques of solution, viscous damping, vibrational isolation, vibration measurement, and control.

Textbooks (most recent edition is recommended):

- Hibbeler, R.C., Engineering Mechanics, Dynamics, Pearson.
- Inman, D.J., Engineering Vibrations, Prentice-Hall.

23-Mechatronics-A7 - Sensors and Actuators

An in-depth examination of sensors and actuators in the context of a mechatronic system. Topics include: determination of required sensor and actuator performance criteria for a mechatronic system; static (e.g., range, accuracy, precision, sensitivity, linearity, resolution) and dynamic (e.g. , rise time, peak time, percent overshoot, settling time, frequency response) system performance characteristics; transfer function models; analysis and selection of common sensors with varying operating principles including: resistive, inductive, capacitive, piezoelectric, and optical; analysis and selection of common actuators including: fluidic actuators, stepper motors, DC motors, piezoelectric actuators, shape memory alloys, and MEMS devices.

Textbooks (most recent edition is recommended):

Primary Text:

- Bishop, Robert H., Mechatronic Systems, Sensors and Actuators: Fundamentals and Modelling, CRC Press.

Secondary Text:

- Nise, N., Control Systems Engineering, Wiley.

Group B - Optional Examinations (three required)

23-Mechatronics-B1 - Digital Signal Processing

Sampling and reconstruction. Discrete-time signals and systems: system input-output and convolution, Z-transform and transfer functions. Discrete-time Fourier transform (DFT) and Fast Fourier transform (FFT). Digital filter design: Design of finite impulse response (FIR) and infinite impulse response (IIR) filters. Considerations for implementation on imbedded systems.

Textbooks (most recent edition is recommended):

- Ifeachor, Emmanuel, and Barrie Jervis, Digital Signal Processing, a Practical Approach, Prentice Hall.
- Mitra, Sanjit, Digital Signal Processing, a Computer-Based Approach, McGraw Hill.

23-Mechatronics-B2 - Advanced Control Systems

Modelling of engineering systems; state variables and transfer function representations. Analytical and numerical solutions of state variable equations. Observability, controllability, stability; classical design, stabilization by pole assignment. Systems with delay. Systems with noise. Computer control, discrete systems. System identification; least squares.

Textbooks (most recent edition is recommended):

- Dutton, Ken, Steve Thompson, and Bill Barraclough, The Art of Control Engineering, Prentice Hall.
- Nise, Norman, Control Systems Engineering, John Wiley.

23-Mechatronics-B3 - Applied Thermodynamics, Fluid Mechanics, and Heat Transfer

Thermodynamics: Review of the fundamental laws of thermodynamics, introductory psychrometry and analysis of the ideal gas compressor cycle, Rankine cycle, Otto cycle, Diesel cycle, Brayton cycle and the vapour compression refrigeration Cycle.
Fluid Mechanics: Review of the principles of fluid mechanics, momentum and energy transfer, thermodynamic analysis, and efficiency definitions. Dimensional analysis and performance evaluation. Application to pumps, fans, compressors, and turbines.
Heat Transfer: Application of the principles of steady and transient conduction heat transfer, natural and forced convection heat transfer and radiation heat transfer. Thermal analysis of heat exchangers.

Textbooks (most recent edition is recommended):

- Moran, M.J., H.N. Shapiro, B.R. Munson and D.P. DeWitt, Introduction to Thermal Systems Engineering: Thermodynamics, Fluid Mechanics, and Heat Transfer, John Wiley and Sons.
- Cengel, Y., Cimbala, J., and Ghajar, A., Fundamentals of Thermal-Fluid Sciences, McGraw Hill

23-Mechatronics-B4 - Statistical Design of Experiments (DOE)

Design of Experiments (DOE) and statistical strategies for experimentation. Data analysis, regression, and ANOVA. Factorial versus one-factor-at-a-time (OFAT) experiments. Design and analysis of 2-level factorial experiments. Fractional factorial design and analysis. Taguchi methods, Response Surface Methodology (RSM), Central Composite Design (CCD), and Box-Behnken Design (BBD). Restricted randomization and hard-to-change factors. Optimal designs, multiple linear constraints, and definitive screening designs. Dimensional analysis and the combined use of DOE and dimensional analysis. Role of DOE within Six Sigma methodology.

Textbooks (most recent edition is recommended):

- Jones, Bradley and Douglas C, Montgomery, Design of Experiments: A Modern Approach, latest edition, Wiley

- Antony, Jiju, Design of Experiments for Engineers and Scientists, ScienceDirect.
- Lye, Leonard, Applications of DOE in Engineering and Science: A Collection of 26 Case Studies, StatEase.

23-Mechatronics-B5 – Robotics

Robot components (sensors, actuators, and end effectors, and their selection criteria); basic categories of robots (serial and parallel manipulators, mobile robots); mobility/constraint analysis; workspace analysis; rigid body kinematics (homogeneous transformation, angle and axis of rotation, Euler angles, cylindrical and spherical coordinates); manipulator kinematics and motion trajectories (displacement and velocity analyses, differential relations, Jacobian matrix); non-redundant and redundant sensing/actuation of manipulators; manipulator statics (force and stiffness); singularities; and manipulator dynamics.

Textbooks (most recent edition is recommended):

- Mark W. Spong, Seth Hutchinson, M. Vidyasagar, Robot Modeling and Control, Wiley.
- Craig, J.J., Introduction to Robotics: Mechanism and Control, Addison-Wesley.

23-Mechatronics-B6 - Power Electronics and Drives

Principles and modelling of electric machines. Servomotors: brushed DC and brushless DC motors (BLDC). Induction and synchronous machines. Power electronic devices and converters: choppers, inverters, cycloconverters, and switched power supplies. Electric drives: torque and speed control. Trapezoidal, sinusoidal, and field-oriented (vector) control of BLDC motors. Stepper motors: unipolar, bipolar, and microstepping motor drives.

Textbooks (most recent edition is recommended):

- Rashid, Muhammad H., Power Electronics: Circuits, Devices and Applications, latest edition. Prentice-Hall.
- Mohan, N, Undeland, T, Robbins, W, Power Electronics – Converters, Applications, and Design. John Wiley.
- Sen, P C., Principles of Electric Machines and Power Electronics, latest edition. Wiley.

23-Mechatronics-B7 - Design and Manufacture of Machine Elements

Theory and methodology related to conceptual design; review of the methods used in stress analysis; simple design factor approach; variable loads; stress concentrations; bolts and bolted joints; welded joints; springs; shaft and bearing design; clutches, brakes, and braking systems.

The role and characterization of manufacturing technology within the manufacturing enterprise is also examined. Topics include an overview of the deformation process, joining processes, consolidation processes, material removal processes, material alteration processes; composites manufacturing, nano- and-microfabrication technologies rubber processing, glass working, coating processes, design for manufacturing, mechanical assembly, electronics packaging and assembly, and production lines; and process selection and planning; quality control systems.

Textbooks (most recent edition is recommended):

- Juvinall, Robert C., and Kurt M. Mershek, Fundamentals of Machine Component Design, Wiley.
- Groover, Mikell P., Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, Wiley.

23-Mechatronics-B8 - Product Design and Development

Modern tools and methods for creative product design and development involving product research, establishment of design parameters, experimentation, development of conceptual alternatives, visualization, evaluation, revision, optimization and presentation. Particular topics include: The engineering design process, development processes and organizations, product planning, identifying customer needs, product specifications, concept generation, concept selection, prototyping, robust design, concept testing, product

architecture, industrial design, design for X (e.g., manufacturing, sustainability, etc.), product development economics, and managing mechatronic-related projects, product lifecycle.

Textbooks (most recent edition is recommended):

Primary Text:

- Ulrich, Karl T. & Steven D. Eppinger, Product Design and Development, McGraw Hill.
- Boothroyd, G., W.A. Knight & Peter Dewhurst, Product Design for Manufacture and Assembly, Marcel Dekker.

Secondary Text:

- Ullman, David G., The Mechanical Design Process, McGraw Hill.

23-Mechatronics-B9 - Computer Integrated Manufacturing and Automation

Production automation and the role of computers in modern manufacturing systems via a comprehensive overview of applications of advanced technologies in modern manufacturing and their business impact on the competitive dimensions of cost, flexibility, quality and deliverability. Particular topics include: facility layout; cellular manufacturing; fundamentals of automation, computer numerical controlled machines for removal and additive manufacturing; programming, material handling and storage, automatically-guided vehicles, flexible manufacturing systems, group technology, programmable logic controllers, concurrent engineering, production planning and control, production activity control systems, automatic identification and data collection, lean and agile manufacturing, computer-aided process planning, forecasting, inventory management and control, quality control, and inspection technologies.

Textbooks (most recent edition is recommended):

- Groover, Mikell P., Automation, Production Systems, and Computer-integrated Manufacturing, Prentice Hall.
- Scheer, A.W., CIM. Computer Integrated Manufacturing-Towards the Factory of the Future, Springer Verlag Link.