Department of Electrical Engineering and Mechatronics
Mechatronics Comprehensive Exam
2025 -

Basics of Mechatronics:

1. Describe the fundamental logic gates with circuit symbols, truth tables, and relay-based switching.
2. Present the algebraic (Boolean algebra) and graphical (Karnaugh-Veitch map) simplification of logical functions.
3. Explain the concepts of term, minterm, and maxterm. What are the disjunctive and conjunctive normal forms? How is the conversion between them performed?
4. What does homogenization mean, and why is it necessary? How is the representation of complex logical functions done using gate circuits?
5. Describe the studied storage elements and flip-flops with circuit diagrams and truth tables! What role do they play in digital technology?
6. Define and briefly explain the following concepts:
    - Real physical system
    - Signal
    - Inputs and outputs
    - System
    - Linear and nonlinear systems (superposition principle)
    - Parameter and variable
    - Distributed and lumped parameter description
    - Deterministic and stochastic system
    - Causality
    - Time-invariant and autonomous system
    - Static and dynamic system
7. Define and briefly explain the following concepts:
    - State, state variable, state indicator
    - State and output equation
    - Canonical state variables
    - System dimension
    - Transient and steady-state
    - Shift operator
8. Using an example, explain what is considered a state machine.

Modelling and Simulation Prototype Technologies I.:

1. What are the advantages of bond graph modeling in mechatronic engineering model development? What mathematical modeling tools do you know for describing a system's static and dynamic behavior?

2. Describe the fundamental bond graph elements: passive one-port elements, active one-port elements, junctions, and special elements.

3. What is the concept of causality? How does it appear in a bond graph? What are preferred and derivative causality? What additional causality rules are applied?

4. What is a time constant? What is a dominant time constant? How can the time constant be determined from the step response of a signal with a dominant time constant?

5. Explain the essence of switching operation. What is the condition for operating a system in switching mode?

6. What general properties characterize a linear system, and what system-theoretical methods can be used to modify these properties?

7. Provide a simple example of how feedback can influence the overall system parameters compared to the original system.

8. What test signals do you know? What is the condition for analyzing a system's behavior using test signals? What is the essence of this method?

9. Given two discrete-time transfer functions ($W_1(z)$ and $W_2(z)$), derive the expression for the resulting transfer function when the two are connected in series, in parallel, and with negative feedback.

10. Using a simple example, explain the transformation rules of block diagrams in the following cases:

    - Moving a branch point after a block
    - Moving a branch point before a block
    - Moving a summation point after a block
    - Moving a summation point before a block

11. With the help of an illustrative diagram, explain how a discrete-time response can be computed for an arbitrary discrete-time input signal using the discrete-time impulse response (discrete-time convolution).

12. Describe the essence of state-space control, its methods, and the formulas applicable for implementation. What is pole placement? How does a state observer work?

Electrotechnics, Electronics I:

1. Which chemical elements are suitable for semiconductors? What semiconductor doping atoms do you know? How does a P-N junction work?
2. Which learned electronic components can be used to implement a voltage amplifier circuit? Describe in detail the characteristics, advantages, and disadvantages of the components. What order of magnitude of amplification can be achieved with different components?
3. What passive electronic filter circuits do you know? What components can be used to build a filter circuit? What determines the cutoff frequency? What does the quality factor (Q-factor) mean? What testing methods do you know to characterize the filter's operation?
4. What electronic components can be used for galvanic isolation? Describe the components in detail.
5. You need to measure the signal from a 0-24V sensor and a 4-20mA sensor using a 0-10V data acquisition card. Explain in detail how you would solve this problem.
6. What standard voltage levels can be generated in a three-phase system? What types of configurations can be used, and what are their advantages and disadvantages? Provide some typical application examples.
7. What optoelectronic components do you know? Describe in detail the operation of a studied component.
8. What does reactive power compensation mean?
9. Describe an integrator circuit! What components does it consist of? How does it work? Where can it be applied?
10. Describe a differentiator circuit! What components does it consist of? How does it work? Where can it be applied?

Applied Automatization I.:

1. Why is the introduction of the generalized derivative necessary? Provide the definition of the generalized derivative.

2. What test signals do you know? What is the condition for analyzing a system's behavior using test signals? What is the essence of this method? Using an illustrative diagram, explain how the system's response to an arbitrary input signal can be calculated in the continuous-time domain using the impulse response (convolution).

3. How can the Fourier series expansion be generalized to non-periodic decaying functions? (Fourier transform) Explain the fundamental differences between Fourier series expansion and the Fourier transform. What difficulties arise when formally trying to apply Fourier series rules to a non-periodic decaying function?

4. What do the Bode and Nyquist diagrams represent? How can they be obtained through measurement? Sketch the Bode and Nyquist diagrams for single-, two-, and three-storage elements, as well as integrating and time-delay elements.

5. Describe the Nyquist stability criterion. What is phase margin (illustrate with a diagram), and how is it related to control system performance?

6. Write the equations for P, PI, PD, and PID controllers in both time and frequency domains.

7. What is the role of the P, I, and D terms in a PID controller? How are the P, I, and D values typically tuned in a PID controller?

8. Compare the operation of P, PD, PI, and PID controllers using a diagram. Assume that a system with multiple energy storage elements needs to be controlled and that you test all four controllers while selecting the time constants according to standard recommendations and adjusting the loop gain so that the phase margin is approximately 50 degrees in each case. Draw the step response of the closed-loop system for each controller and explain the key differences.

9. Explain how controller saturation affects the operation of a PI controller. Describe the Ziegler-Nichols method for experimentally tuning a PID controller.

Applied Automatization II.:

1. Describe the general architecture of PLCs. How would you categorize different types of PLCs?
2. Explain the execution cycle of a PLC and detail why it is necessary.
3. What input and output modules do you know, and what are their main parameters? (At least four should be known.)
4. Describe the operation of digital input and output modules.
5. Describe the operation of analog input and output modules.
6. What devices can provide input signals to a PLC, and what devices can be connected to the PLC outputs? Describe these devices in detail.
7. What program organization units (POUs) do you know, and what are the key differences between them?
8. List the standardized PLC programming languages. Explain the language(s) used in the practical exercises.
9. What predefined program organization units (POUs) do you know? Describe their functionality in detail.
10. Why might it be necessary to create custom program organization units (POUs)? What are the advantages of using POUs?

Electropneumatics and Electrohydraulics:

1. Solutions for electropneumatic and pneumatic sequential control (cascade, step chain, stepper, relay-based solutions, etc.). Advantages of PLC control.
2. Electropneumatic and pneumatic switching circuits: direct/indirect control, self-holding circuits.
3. Types and operation of sensors used in electropneumatics (Reed, optical, inductive, capacitive, pressure sensors).
4. Types and operation of relays (remanent, time-delay, protective relays, etc.) / protective circuits for inductive loads.
5. Structure and operation of directional control EP valves (2/2, 3/2, 4/2, 5/2, 5/3), pilot control.
6. Types of energy in hydraulic systems, power, and efficiency (pressure, potential, kinetic, thermal energy and their relationships), cavitation phenomenon.
7. Methods for modifying actuator speed in electrohydraulic and hydraulic systems (viscosity-dependent and independent throttling), proportional hydraulics.
8. Operation and application of pressure control valves in hydraulic systems (pressure regulators, pressure relief valves).
9. Components of a hydraulic power unit, their functions, and types (pump, tank, filters, coolers, heaters).
10. Types and characteristics of flow, measurement parameters; viscosity; properties of hydraulic fluids.

Robots and Robotics Technology:

1. Definition and relationships of degrees of freedom and constraints. Coordinate geometry description of translational and rotational joints.
2. Presentation of robotic kinematic chains: Serially chained and parallel structure robots, open and closed kinematic chains.
3. Basic configurations of robot manipulators: Classification, structure, recommended architecture for specific tasks, advantages, and disadvantages of each architecture.
4. Introduction to robot coordinate systems, their functions, and coordinate geometry relationships. Role and definition of the tool center point (TCP).
5. Description of joint and world coordinates of robots, Denavit-Hartenberg coordinate transformation, and the concept of redundancy.
6. Explanation of direct and inverse kinematics calculations of robots. Introduction to the homogeneous transformation matrix and the Jacobian matrix.
7. The role, possibilities, and process of tool and workspace calibration.
8. Description and specification of basic motion instructions for robots (linear, joint-type, and circular motion). The process of teaching robot manipulators and the principles of selecting appropriate motion instructions.
9. Overview of robot safety functions, use of the Teach Pendant (manual controller), and the role of two-hand operation.
10. Presentation of the singularity phenomenon, its occurrence, mathematical background, and practical significance.

Mechatronic Devices:

1. List and evaluate the input and output characteristics of the sensor cube and categorize them. What is the Miller index?
2. Characterize the static characteristics of sensors. What are the most important features and sources of error in a sensor? What is the hysteresis phenomenon?
3. What is the operating principle of capacitive proximity switches? Draw and evaluate the circuit diagram.
4. What is the operating principle of optical sensors? Evaluate the advantages and disadvantages of different application modes.
5. What is the Reynolds number, and what is it used for? Write down the Bernoulli equation and evaluate it. What does the continuity equation express?
6. Why is the calibration of measuring instruments and measurement systems necessary? What are the most important expectations of calibration?
7. What is the operating principle of Resolver-type angle sensors? Write down the operational equations.
8. What is "Ingress Protection" (IP)? Why is it important, and what components does it include?
9. Explain the principles of thermal imaging measurements, their key characteristics, and the effects of error sources arising from the measurement setup.

Measurement and Data Acquisition:

1. Evaluate measurement results in terms of precision and accuracy (correctness). What is the normal distribution function? Draw different cases for: m=0 and σ=1, σ=10, σ=0.5; m=2 and σ=0.4, σ=2.
2. What is Euler’s number and its significance in evaluating measurement processes? Using it, describe the "sin x" and "cos x" functions and evaluate them.
3. What are the most important physical characteristics and values of the electromagnetic spectrum? What is a transverse wave? What is polarization, and what is the difference between horizontal and linear polarization?
4. What is the SI (Système International d'Unités) system? What is its purpose? What are its base and supplementary units?
5. What is measurement, and what components make up a measurement system? Briefly evaluate these components. What is the difference between measurement and control systems?
6. What is the decibel (dB), and why is it important? What are the values in base-10 logarithmic notation for: 3dB, -10 dBm, 20 dBi, -3 dB, and 10 dBW? Arrange these values in ascending order.
7. Compare capacitive, piezoresistive, and piezoelectric sensors based on price, application, design simplicity, response time, power consumption, and high-temperature tolerance.
8. If the measured value is 4.95 [mA] and the correct value is 5 [mA], what is the absolute error? An analog potentiometer has a measurement range of 0-15V with a relative measurement error of < ±0,5 %. Calculate the relative error for measurements of 12V and 4V.

Electrical Machines and Drives:

1. Describe and interpret the three fundamental laws of classical electrical machines. List the types of torque in electromagnetic motors. What types of motion can be distinguished in electric motors? Classify motors based on their energy transmission medium. Why are electromagnetic motors made of ferromagnetic materials?

2. Using diagrams, explain how a rotating magnetic field can be generated. How can a sinusoidal air-gap field distribution be created using windings?

3. What types of torque exist in electromagnetic motors? Explain the principle of virtual work and how torque can be calculated based on it.

4. Provide the classification criteria for electromagnetic radial motors and discuss the advantages and disadvantages of each category.

5. Write down the general equation of cylindrical torque for multiphase motors and interpret the frequency condition. Explain how the frequency condition is met for the fundamental motor types:

    - Cylindrical torque of single-phase motors
    - Why are DC motors classified as multiphase motors in the unified machine theory?
    - Cylindrical torque of multiphase motors
    - DC motors supplied with direct current
    - DC motors supplied with alternating current
    - Motors with a rotor excited by direct current or permanent magnets
    - Asynchronous (induction) motors

6. Explain the operating principle of an Ultrasonic Motor (USM).

7. Compare the working principles of brushed and brushless DC motors.

8. Compare the operation of stepper motors and switched reluctance motors. List the basic types of stepper motors. What are full-step and half-step modes in stepper motors?

9. For DC drives, describe the different operating modes in each quadrant of the speed/torque plane. What are the directions of energy flow in each mode?

10. Why were externally excited brushed DC motors traditionally used in servo drives? How has this changed today? Explain the concept of dual-loop speed control in DC motors.