National Technical University of Ukraine
Igor Sikorsky Kyiv Polytechnic Institute "

Department of
Electromechanical Systems
Automation and Electrical
Drives

# AUTOMATIC CONTROL THEORY

## Working program of the academic discipline (Syllabus)

| Details of the academic discipline | |
|---|---|
| **Level of higher education** | ***First (undergraduate)*** |
| **Discipline** | *14 "Electrical engineering"* |
| **Specialty** | *141 "Electric power engineering, electrical engineering and electromechanics"* |
| **Educational program** | *ELECTROMECHANICAL AUTOMATION SYSTEMS, ELECTRIC DRIVE AND ELECTRIC MOBILITY* |
| **Discipline status** | *Normative* |
| **Form of education** | *Ochna* |
| **Year of training, semester** | *2nd year, spring semester* |
| **Scope of the discipline** | *240 hours / 8 ECTS credits* |
| **Semester control/ control measures** | *Exam/MKR/RGR* |
| **Class schedule** | *http://rozklad.kpi.ua* |
| **Language of teaching** | *Ukrainian* |
| **Information about the head of the course / teachers** | Lecturer 1: *Ph.D. , Assoc. Priymak Bohdan Ivanovich, 0681213423*<br>Lecturer 2: *Doctor of Technical Sciences , Prof. Olga Ivanivna Tolochko, 0994945473*<br>Practical: *Ph.D. , Assoc. Priymak Bohdan Ivanovich*<br>Laboratory: *Doctor of Technical Sciences, Prof. Olga Ivanivna Tolochko* |
| **Placement of the course** | https://classroom.google.com/c/NTE1NzU1OTQwMDE4?cjc=jpw7sru |

## Program of the academic discipline (credit module)

### 1. Description of the academic discipline, its purpose, subject of study and learning outcomes

*The program of the discipline "Theory of automatic control" was compiled in accordance with the educational and professional program "Electromechanical systems of automation, electric drive and electromobility " of the bachelor's training in specialty 141 - "Electric power engineering, electrical engineering and electromechanics".*

**The goal of the educational discipline** *is to form students of the following abilities: to apply linearization methods to obtain linearized mathematical models of non-linear control objects; use transfer functions and state space equations for the mathematical description of links and systems; apply root, algebraic and frequency methods to study the stability of linear automatic systems; analyze transitional and established processes to determine the quality of SAC functioning; carry out the synthesis of regulators and corrective devices to obtain the necessary properties of closed SACs.*

**The subject of the educational discipline** *is the principles and methods of construction, calculation and research of linear continuous automatic control systems used for the automation of electromechanical objects of various purposes.*

***Program learning outcomes:***

*Competencies: (From K01) ability to abstract thinking, analysis and synthesis; (ZK03) ability to communicate in the state language both orally and in writing; (ZK05) ability to search, process and analyze information from various sources; (ZK06) ability to identify, pose and solve problems; (ZK07) ability to work in a team; (ФК04) the ability to solve complex specialized tasks and practical problems related to problems of metrology, electrical measurements, operation of automatic control devices, relay protection and automation; (FC10) awareness of the need to constantly expand one's own knowledge about new technologies in electric power, electrical engineering and electromechanics; (FK12) the ability to use mathematical methods and methods of the theory of automatic control in the study of linear and nonlinear systems, to analyze quality indicators, to synthesize regulators, to compile and analyze structural diagrams of automatic control systems; (FC13) the ability to use modeling software packages for analysis, synthesis and research of electromechanical automation systems and electric drives.*

*Knowledge: (PRN02) to know and understand the theoretical foundations of metrology and electrical measurements, the principles of operation of automatic control devices, relay protection and automation, to have the skills to perform appropriate measurements and use these devices to solve professional tasks; (PRN20) to know and understand the principles of control of linear, non-linear and discrete automatic control systems; (PRN26) to know and understand the laws of transformation of structural diagrams, typical control laws, methods of studying the stability of linear automatic control systems, typical libraries of Simulink blocks , basics of programming in M-files.*

*Ability: ( PRN06) to apply application software, microcontrollers and microprocessor technology to solve practical problems in professional activities; (PRN08) choose and apply suitable methods for the analysis and synthesis of electromechanical and electric power systems with specified indicators; (PRN10) find the necessary information in scientific and technical literature, databases and other sources of information, evaluate its relevance and reliability; (PRN11) communicate freely about professional problems in national and foreign languages orally and in writing, discuss the results of professional activity with specialists and non-specialists, argue their position on debatable issues; (PRN18) to learn independently, acquire new knowledge and improve skills in working with modern equipment, measuring equipment and application software.*

## 2. Pre-requisites and post-requisites of the discipline (place in the structural and logical scheme of training according to the relevant educational program)

*To study the disciplines "Theory of Automatic Control" precede the basic educational components "Higher Mathematics" and "General Physics". Competencies, knowledge and skills acquired during the study are necessary for further study of the disciplines "Electric drive", "Automated electric drive", "Control of electric drives", "Electromechanical systems of typical technological applications", "Modeling of electromechanical systems", " Electromobility ".*

## 3. Content of the academic discipline

*The educational discipline consists of two parts, which, respectively, are taught by two teachers.*

*Part I of the discipline is structurally divided into **4 sections** .*

***1. Automatic control systems. Their structure, principle of operation, mathematical models***

*Topic 1.1. General concepts and terms. Brief historical information.*
*Topic 1.2. Automatic control systems. Their types.*

*Topic 1.3. Mathematical models of dynamic systems.*
*Topic 1.4. Structural schemes of SAC and their transformations.*
*Topic 1.5. Forms of recording transfer functions.*
*Topic 1.6. Method of state variables. Description of SAC in state space.*
*Topic 1.7. Transition between transfer functions and equations of state.*
*Topic 1.8. Manageability and observability of SAC. Canonical forms equations of state.*
*Topic 1.9. Solution of state equations. Structural transformations SAC models .*
*Topic 1.10. The main features and tasks of YES. Linearization of mathematical models.*

***2. Mathematical description of linear continuous automatic control systems***

*Topic 2.1. Typical links of SAC, their description and time characteristics.*
*Topic 2.2. Frequency characteristics of SAH.*
*Topic 2.3. Frequency and logarithmic frequency characteristics of typical SAC links.*
*Topic 2.4. Frequency characteristics of groups of links. Features of non-minimally phase links.*
*Topic 2.5. Equations of dynamics, transfer functions and AFC of stabilization, software and tracking systems.*

***3. Stability of linear continuous automatic control systems***

*Topic 3.1. Concept of stability of SAH.*
*Topic 3.2. Study of stability based on the roots of the characteristic equation.*
*Topic 3.3. Algebraic stability criteria.*
*Topic 3.4. Nyquist's frequent stability criterion .*
*Topic 3.5. The Nyquist criterion in logarithmic form. Structurally unstable systems.*

***4. Quality of automatic control systems. Evaluation and quality improvement***

*Topic 4.1. Quality indicators of SAC functioning. Direct method of quality analysis.*
*Topic 4.2. Approximate methods of SAC quality analysis. Root methods.*
*Topic 4.3. The root hodograph method . Integral and frequency methods of quality research.*
*Topic 4.4. Errors in SAC. Typical operating modes and system quality.*
*Topic 4.5. Improvement of SAC quality indicators.*
*Topic 4.6. Accuracy of SAC in stable dynamic modes of operation .*
*Topic 4.7. Synthesis of SAC by the method of logarithmic amplitude-frequency characteristics.*
*Topic 4.7. Synthesis of modal SACs.*

*The course of the II credit module has **1 section** .*

***1. Mathematical methods and programming in MATLAB for control theory***

*Topic 1.1. Basics of work in MATLAB .*
*Topic 1.2. Operations with matrices and vectors.*
*Topic 1.3. Graphic tools of the MATLAB package.*
*Topic 1.4. Fundamentals of programming in the MATLAB environment .*
*Topic 1.5. Linear algebra operations.*
*Topic 1.6. Operations with power polynomials.*
*Topic 1.7. Performing structural transformations in the MATLAB environment.*
*Topic 1.8. Fundamentals of mathematical modeling in the Simulink environment .*
*Topic 1.9. Types of mathematical description of linear dynamic systems. Creation and mutual transformations of linear dynamic objects with different forms of mathematical description.*
*Topic 1.10. Analysis of linear dynamic systems by location of their zeros and poles.*

*Topic 1.11. Analysis of time characteristics of linear dynamic objects. Determination of quality indicators of transient processes.*
*Topic 1.12. Frequency analysis of linear dynamic systems in the environment of the MATLAB package.*
*Topic 1.13. Approximation and interpolation in MATLAB.*
*Topic 1.14. Numerical integration.*
*Topic 1.15. Numerical methods of solving differential equations.*
*Topic 1.16. Numerical methods of solving transcendental equations and their systems.*

## 4. Educational materials and resources

*Main information resources for part I of the academic discipline:*


1. *Priymak B.I. Theory of automatic control . Linear systems [Electronic resource] : Study guide. – Kyiv: KPI named after Igor Sikorskyi, 2023 . - 310 s . Access mode: https://ela.kpi.ua/handle/123456789/55419*
2. *Popovych M.G., Kovalchuk O.V. Theory of automatic control: Textbook. –2nd ed., revision. And add . –K.: Lybid, 2007. –656 p.*
3. *Ogata K. Modern control engineering , Prentice-Hall , 2010, 905 p.*
4. *Phillips C., Harbor R. Feedback control systems, Prentice-Hall, 2000, 658 p.*


*Additional information resources for part I of the academic discipline:*


5. *Theory of automatic control : method. in fairy tales for practical classes on discipline [Electronic resource] / Compilation. B.I. Adoptee. - K.: NTUU "KPI", 2012. - 71 p. – Access mode: http://ela.kpi.ua/handle/123456789/2208*
6. *Theory of automatic control . Course work [Electronic resource]: ed . help for studies specialty 141 " Electric power, electrical engineering and electromechanics" / Composer: O. I. Tolochko, S. M. Peresada, B. I. Priymak - Kyiv: KPI named after Igor Sikorskyi, 2022. – 163 p . Access mode: https://ela.kpi.ua/handle/123456789/48912*
7. *Dorf R., Bishop R. Modern control systems, Addison-Wesley, 2016, 1032 p .*
8. *Nise NS Control Systems Engineering , Wiley, 2018. – 800 p .*


*Main information resources for part II of the academic discipline:*


1. *Tolochko O.I. Mathematical methods in electromechanics [Electronic resource]: teaching . help For students of specialty 141 "Electric power engineering, electrical engineering and electromechanics". – Kyiv: KPI named after Igor Sikorskyi, 2020. – 212 p.*
2. *Mathematical methods in electromechanics and control theory. Methodical instructions for laboratory work for students of specialty 141 - "Electric power engineering, electrical engineering and electromechanics" specialization "Electromechanical systems of automation and electric drive" Incl .: O.I. Tolochko. – Kyiv: KPI named after Igor Sikorskyi, 2016. – 81 p.*
3. *Gaev E.O., Nesterenko B.M. Universal mathematical package MATLAB and typical problems of computational mathematics. Educational guide . - K.: NAU, 2004. - 176 p.*
4. *Lazarev Yu.F. MatLab 5. x . - K.: BHV Publishing Group , 2000. - 384 p.*


*Additional information resources for part II of the academic discipline:*


5. *Zadachyn V.M., Konyushenko I.H. Numerical methods. Study guide. - Kharkiv. View. HNEU named after S. Kuznetsia , 2014. – 180 p.*
6. *Feldman L.P., Petrenko A.I., Dmytrieva O.A. Numerical methods in computer science. - K.: BHV Publishing Group, 2006. - 480 p.*

7. *MATLAB, Simulink , Simpowersystem . Fundamentals of programming [Electronic resource]: training . Help For students of the specialty 141 "Electricity, electrical engineering and electromechanics" from the discipline "Packages of applied programs, part I", specialization "Management systems for production and distribution of electric power" / O. I. Tolochko; KPI named after Igor Sikorsky. – Kyiv: KPI named after Igor Sikorskyi, 2019. – 226 p.*
8. *Study guide for the discipline "Modeling and analysis of electromechanical systems in MATLAB" / O. I. Tolochko. - Kyiv, 2017. - 275 p.*
9. *Lozynskyi A., Moroz V., Paranchuk Ya. Solving problems of electromechanics in the environment of MathCAD and MATLAB packages : teaching . Manual. - Lviv: Publishing House of the State University "Lviv Polytechnic", 2000 - 166 p.*

## Educational content

### 5. Methods of mastering an educational discipline (educational component)

***Lecture classes in part I of the credit module***

| *No s/p* | *The name of the topic of the lecture and a list of main questions (list of didactic tools, links to information sources)* |
|---|---|
| *1* | ***General concepts and terms. Brief historical information.*** *Basic definitions. Automation and automation. A brief history of the development of automation . General information about cybernetics .*<br>*Literature [1], [2], [4 ]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *2* | ***Automatic control systems. Their types.*** *Automatic control system and its elements. SAC with feedback. Functional diagram. Principles of automatic control. The main types of SAC.*<br>*Literature [1], [2], [4]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *3* | ***Mathematical models of dynamic systems.*** *Models based on differential equations. Description of systems using transfer functions. The operator form of differential equations. Examples.*<br>*Literature [1], [2], [3]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *4* | ***Structural schemes of SAC and their transformation*** *. Rules for transforming structures. Examples of simplification of structural schemes. Transfer functions of SAC by external actions.*<br>*Literature [1], [2], [3]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *5* | ***Forms of recording transfer functions.*** *Writing transfer functions in polynomial form, as a product of prime factors, as a sum of prime fractions.*<br>***Method of state variables. Description of SAC in state space.*** *A general concept of the state variable method. Equation of state of dynamic systems.*<br>*Literature [1], [2], [3]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *6* | ***Transition between transfer functions and equations of state*** *. Obtaining equations of state based on transfer functions and structural schemes. Determination of transfer functions by state equations.*<br>*Literature [1], [2], [4]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |

| | |
|---|---|
| 7 | ***Manageability and observability of SAC. Canonical forms of state equations*** *. Controllability and observability of linear systems. Similarity transformations and canonical forms of state equations.*<br>*Literature [1], [2], [3]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| 8 | ***Solution of state equations. Structural transformations of SAC models*** *. Methods of solving state equations. Structural transformations of SAC models in the state space.*<br>*Literature [1], [2], [3]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| 9 | ***The main features and tasks of YES. Linearization of mathematical models*** *. Statics and dynamics of SAC. Compilation of dynamics equations and their recording form. Linearization of mathematical models in TAK. Examples.*<br>*Literature [1], [2], [4]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| 10, 11 | ***Typical links of SAC, their description and time characteristics.*** *Peculiarities of the dynamics equations of SAC links. Typical links, their description and dynamic properties.*<br>*Literature [1], [2], [4]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| 12 | ***Frequency characteristics of SAH*** *. Amplitude-phase frequency characteristics. Experimental method of construction of AFC. Logarithmic frequency characteristics.*<br>*Literature [1], [2]. SRS: Elaboration of lecture material, preparation for* practical and *laboratory* classes *, drawing up reports on laboratory work .* |
| 13 | ***Frequency and logarithmic frequency characteristics of typical SAC links*** *. Literature [1], [2], [4]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| 14 | ***Frequency characteristics of groups of links. Features of non-minimum phase links*** *. Frequency characteristics of various link connections. Construction of logarithmic characteristics of a group of links. Minimum-phase and non-minimum -phase links.*<br>*Literature [1], [2], [4]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| 15 | ***Equations of dynamics, transfer functions and AFC of stabilization, software and tracking systems.*** *Equations of dynamics, transfer functions and AFH of software and tracking systems. Equations of dynamics, transfer functions and AFC of stabilization systems .*<br>*Literature [1], [2], [3]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| 16 | ***The concept of stability of SAH*** *. General concept of system stability* ***.*** *Stability in the small, in the big, in general. Stability of undisturbed movement.*<br>***Study of stability based on the roots of the characteristic equation.*** *Stability analysis by the roots of the characteristic equation. Limit and safety margin .*<br>*Literature [1], [2], [3]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| 1 7 | ***Algebraic stability criteria*** *. The Raus -Hurwitz stability criterion . Ljenar - Schipar stability criterion . The general method of studying the influence of parameters on the stability of the system according to algebraic criteria.*<br>*Literature [1], [2]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| 18 | ***Nyquist's frequent stability criterion*** *. Peculiarities of the Nyquist criterion . Proof of the criterion. Determination of the margin of stability according to the Nyquist criterion .* |

| | |
|---|---|
| | *Literature [1], [2], [3]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *19* | ***The Nyquist criterion in logarithmic form. Structurally unstable systems.*** *The Nyquist criterion in logarithmic form. Features of structurally unstable SAC. Ways to eliminate structural instability.*<br>*Literature [1], [2]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *20* | ***Quality indicators of SAC functioning. Direct method of quality analysis*** *. Accuracy indicators, system statics . Indicators of the quality of transient processes. Quality analysis by solving the dynamics equation of a closed system.*<br>*Literature [1], [2], [4]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *21* | ***Approximate methods of SAC quality analysis. Root methods.*** *Study of the quality of the location of the roots. Analysis of the quality of SAC according to parameter zone diagrams. Evaluation of SAC quality indicators by poles and zeros of the transfer function.*<br>*Literature [1], [2]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *22* | ***The root hodograph method . Integral and frequency methods of quality research*** *. Root hodograph method. Integral methods of quality assessment. Analysis of the quality of SAC in the frequency domain. An example of determining frequency indicators of SAC quality.*<br>*Literature [1], [2], [3]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *23* | ***Errors in SAC. Typical operating modes and system quality.*** *Static and dynamic SAC errors. Typical operating modes of automatic systems. Analysis of the quality of SAC by the method of error coefficients.*<br>*Literature [1], [2]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *24* | ***Improvement of SAC quality indicators*** *. The main ways of increasing the accuracy of SAC . Quality improvement by closing SAC. Basic governing laws and regulators. Complex control laws and regulators.*<br>*Literature [1], [2], [4]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *25* | ***Accuracy of SAC in stable dynamic modes of operation .*** *The mode of changing the external action at a constant speed. Mode of change of external action with constant acceleration.*<br>*Literature [1], [2]. SRS: Elaboration of lecture material, preparation for practical and laboratory classes, preparation of laboratory work reports .* |
| *26* | ***Synthesis of SAC by the method of logarithmic amplitude-frequency characteristics .*** *Principles of building the desired LAH . Simplified construction of the desired LAH Synthesis of a sequential correction link. An example .*<br>*Literature [1], [ 2 ], [ 3 ] , [4]. SRS: Elaboration of lecture material, preparation for* practical and *laboratory* classes *, drawing up reports on laboratory work .* |
| *27* | ***Synthesis of modal SACs .*** *The principle of modal control. Ackerman's formula. Standard characteristic polynomials of closed systems. An example of the synthesis of a modal control system.*<br>*Literature [1], [ 2 ], [ 3 ] , [4]. SRS: Elaboration of lecture material, preparation for* practical and *laboratory* classes *, drawing up reports on laboratory work .* |

***Lectures in part II of the credit module***

| No s/p | The name of the topic of the lecture and a list of main questions (list of didactic tools, links to information sources) |
|---|---|
| 1 | ***Introduction*** *. Purpose and tasks of the discipline; examples of problems in the field of electrical engineering, mechanics, electromechanics and control theory that require the use of numerical methods. Characteristics of the software intended for solving mathematical and applied engineering and technical problems by numerical methods. Characteristics of recommended literary sources.*<br>*Literature: [1], p. 3 - 6 , 17-19; [ 3 ], p. 9-22.*<br>*Tasks on SRS. Development of lecture material, preparation for laboratory works.* |
| 2 | ***Basics of work in MATLAB*** *. Characteristics of the package and its file system; data types, constants and variables; explicit and implicit assignment; elementary functions; demonstrations; assistance organization; generation of vectors and matrices .*<br>*Literature: [1], p. 6-21; [4], p. 13-25.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| 3 | ***Operations with matrices and vectors*** *. Arithmetic operations; determination of dimensions; basic functions of mathematical analysis of vectors and matrices; manipulation of matrices.*<br>*Literature: [1], p. 22 - 27 ; [ 4 ], p. 26-41.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| 4 | ***Graphic tools of the MATLAB package*** *. Rules for constructing two-dimensional graphs by basic operators; signing of axes and graphs; management of styles and colors of the image of lines and markers on graphs; control of the coordinate system; management of graphic windows; construction of graphs in polar coordinates; means of special graphics; means of 3-dimensional graphics.*<br>*Literature: [1], p. 28 - 40, 67-81 ; [ 4 ], p. 66-74, 100-105.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| 5 | ***Fundamentals of programming in the MATLAB environment .*** *Basic rules for creating and executing script files; main operators; rules for creating and executing m-functions.*<br>*Literature: [1], p. 51 - 66 ; [4], p. 75-79, 82-89.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| 6 | ***Operations of linear algebra.*** *Methods of calculating the determinant of a matrix, solving a system of linear equations, calculating adjoint and inverse matrices; calculation of stable modes in electric circuits*<br>*Literature: [1], p. 82 - 98 ; [4], p. 50-57.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| 7 | ***Operations with polynomials .*** *The concept of a power polynomial; calculation of the value of a power polynomial; derivation of a power polynomial; operations with power polynomials; calculation of zeros of a power polynomial; determining the coefficients of a power polynomial by its zeros.*<br>*Literature: [1], p. 99 - 110 ; [4], p. 43-45.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |

| | |
|---|---|
| 8 | ***Performing structural transformations in the MATLAB environment .*** *Application of operations on polynomials for equivalent SAC transformations . Getting to know the Extended folder tools Symbolic Toolbox of the MATLAB package ; description of symbolic variables; equivalent transformations of symbolic expressions; display of symbolic expressions on the screen; substitution of numerical values in symbolic expressions. Familiarity with the functions of equivalent transformations of the Control application Toolbox of the MATLAB package .*<br>*Literature: [7], p. 226-230.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| 9 | ***Types of mathematical description of linear dynamic systems. Creation and mutual transformations of linear dynamic objects with different forms of mathematical description.*** *Transfer functions in polynomial form, in the form of decomposition into zero poles (sequential decomposition) and in the form of decomposition into the sum of simple fractions (parallel decomposition). Description of SAC in the space of states. Determination of the mathematical description of SAC according to its structural mathematical model.*<br>*Literature: [8], p. 242-247.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports.* |
| 10 | ***Fundamentals of mathematical modeling in the Simulink environment .*** *Familiarity with the basic rules for creating structural models in the Simulink environment ; acquaintance with continuous dynamic links, blocks for forming step and sinusoidal signals, blocks for fixing and visualization of modeling results; determination of modeling parameters and model properties.*<br>*Literature: [7], p. 132-147.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| 11 | ***Analysis of linear dynamic systems by location of their zeros and poles.*** *Forms of representation of complex numbers; representation of complex numbers on a plane in Cartesian and polar coordinates; operations on complex numbers; determination of zeros and poles from the transfer function of the object under study and their graphic display using basic graphic MATLAB functions and functions of the Control application Toolbox .*<br>*Literature: [8], p. 259-262.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| 12 | ***Analysis of time characteristics of linear dynamic objects.*** *Direct and inverse Laplace transform. Construction of responses of linear SACs to typical input signals and finding analytical expressions for their construction , relationship between them. Determination of quality indicators of transient processes.*<br>*Literature: [8], p. 248-252.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| 13 | ***Frequency analysis of linear dynamic systems in the environment of the MATLAB package.***<br>*Calculation and construction of frequency characteristics using the functions of the core of the MATLAB package and the tools of the Control application Toolbox . Determination of* |

| | |
|---|---|
| | *stability reserves according to Bode and Nyquist diagrams . Construction of asymptotic LFCs in MATLAB.*<br>*Literature: [8], p. 253-258.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| *10* | ***Analysis of time characteristics of linear dynamic objects. Determination of quality indicators of transient processes.*** *Determination of the mathematical description of SAC according to its structural mathematical model. Calculation and construction of transient and weight functions and response to a linear input signal.*<br>*Topic 1.12. Frequency analysis of linear dynamic systems in the environment of the MATLAB package.*<br>*Topic 1.13. Approximation and interpolation in MATLAB.*<br>*Topic 1.14. Numerical integration.*<br>*Topic 1.15. Numerical methods of solving differential equations.*<br>*Topic 1.16. Numerical methods of solving transcendental equations and their systems.* |
| *14* | ***Approximation and interpolation in Matlab .*** *general concepts of smoothing functions; approximation by power polynomials by the method of least squares; global and local interpolation by power polynomials; cubic spline interpolation .*<br>*Literature: [1], p. 111 - 126 ; [3], p. 58-60.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports* |
| *15* | ***Numerical integration.*** *Basic concepts of definite integrals and their calculation; methods of rectangles, trapezoids, Simpson; estimation of numerical integration errors; choice of integration step; numerical integration methods with automatic step selection.*<br>*Literature: [1], p. 127-134; [3], p. 104-110.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports.* |
| *16* | ***Numerical methods of solving differential equations.*** *Review of numerical methods for solving differential equations; Runge-Kutt methods ; solving differential equations using the algorithmic language of the MATLAB package ; examples of calculation of transient processes in electrical linear and non-linear circuits in the MATLAB package.*<br>*Literature: [1], p. 145-169; [3], p. 111-138.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports.* |
| *17* | ***Numerical solution of transcendental equations and their systems in Matlab .***<br>*Separation of roots of equations; refinement of roots by methods of bisections , chords, tangents, simple iterations; application of Matlab functions to perform these operations.*<br>*Literature [1], pp. 170-179; [3], pp. 98-106.*<br>*Tasks on SRS. Elaboration of lecture material, preparation for laboratory work, preparation of laboratory work reports.* |

***Practical classes in part I of the credit module***

| No s/p | *Name of the subject of the lesson and list of main questions* |
|---|---|
| *1* | ***Mathematical description of links and systems*** *.* ***Typical links*** *. Differential equations of links and control systems. Equations of dynamics of typical links and their transfer* |

| | |
|---|---|
| | *functions. Examples of mathematical description of links with mechanical elements, electrical links with RLC elements. Literature [1], [2], [4].* |
| *2* | ***Structural schemes of SAC and their transformations.*** *Rules for drawing up and transforming structural diagrams. Reduction of complex structural schemes to single-circuit ones . Obtaining the transfer functions of the SAR according to external actions on the system: according to the task and according to disturbances. Literature [1], [2], [4].* |
| *3* | ***Mathematical description of SAC in state space*** *. Vector-matrix equations of state. Obtaining equations of state based on transfer functions and structural schemes. Detailed structures of generalized links of the 1st and 2nd order. Determination of transfer functions by state equations. Literature [1], [2], [4].* |
| *4* | ***Compilation and analysis of structural diagrams. Static properties of SAC*** *. Compilation of the structural diagram of the system according to the description of its elements. Determination of static SAC indicators by transfer functions. The influence of feedback on static errors. Example of motor speed SAR with angular velocity and armature current feedback. Literature [1], [2], [4].* |
| *5* | ***Frequency characteristics of links and systems.*** *Construction of frequency characteristics of links and systems. Frequency characteristics of typical links. Logarithmic frequency characteristics of links and systems. Determination of parameters of transfer functions by logarithmic frequency characteristics. Literature [1], [2], [4].* |
| *6* | ***Study of the stability of SAC using the root method and algebraic criteria.*** *Stability analysis by the roots of the characteristic equation. Algebraic stability criteria. Use of Hurwitz, Ljenar-Schipar criteria . Literature [1], [2], [5].* |
| *7* | ***Nyquist's frequent stability criterion .*** *Nyquist stability criterion . Cases of stable and unstable open system. Stability reserves by amplitude and phase. Analysis of stability of SAH using the Nyquist test in normal and logarithmic form. Literature [1], [2], [5].* |
| *8* | ***Evaluation of the quality of SAC.*** *The main indicators of the quality of SAR and their analysis. Methods of error coefficients. Static and dynamic errors. Fixed modes for typical actions. Introducing astatism into the system. Literature [1], [2], [5].* |
| *9* | ***Synthesis of sequential correction devices by the LAX method.*** *Methodology of synthesis. The principles of building the desired LAX according to the necessary indicators of management quality. Literature [1], [2], [3], [5].* |

***Laboratory classes in part I of the credit module***

| *No s/p* | *The name of the laboratory work* | *Number audio hours* |
|---|---|---|
| *1* | *Study of time and frequency characteristics of typical links of automatic control systems.* | *4* |
| *2* | *Study of established modes of operation of automatic regulation systems .* | *4* |
| *3* | *Study of the stability and quality of the linear automatic control system.* | *4* |
| *4* | *Synthesis of sequential corrective links of linear SACs .* | *4* |
| *5* | *Colloquium on laboratory works* | *2* |

***Computer workshop in part II of the credit module***

| *No s/p* | *The name of the laboratory work* | *Number audio hours* |
|---|---|---|
| *1* | *Familiarity with the Matlab programming system* | *2* |

| | | |
|---|---|---|
| *2* | *Operations on matrices. Functions of mathematical analysis* | *2* |
| *3* | *Graphic tools of the Matlab package* | *2* |
| *4* | *Matrix algebra operations* | *2* |
| *5* | *Operations on power polynomials* | *2* |
| *6* | *Approximation and interpolation of tabular functions* | *2* |
| *7* | *Numerical integration* | *2* |
| *8* | *Solving nonlinear equations and their systems in Matlab* | *4* |

### 6. Student's independent work

| *No. z/p* | *Type of independent work* | *Number hours of SRS* |
|---|---|---|
| *1* | *Preparation for classroom classes* | *40* |
| *2* | *Preparation for MKR* | *4* |
| *3* | *Implementation of RGR* | *12* |
| *4* | *Preparation for the exam* | *30* |
| | *Together* | *96* |

## Policy and control

### 7. Policy of academic discipline (educational component)

*The system of requirements that the teacher sets before the student:*

- *rules for attending classes: in accordance with Order 1-273 dated 14.09.2020, it is prohibited to evaluate the presence or absence of the winner at the classroom class, including the awarding of incentive or penalty points. According to the RSO of this discipline, points are awarded for the corresponding types of educational activity in lectures, practical and laboratory classes.*
- *rules of behavior in classes: the student has the opportunity to receive points for the appropriate types of educational activity in lectures, practical and laboratory classes, provided for in the RSO of the discipline. The use of means of communication to search for information on the teacher's Google Drive, on the Internet, in a distance course on the Sikorsky platform is carried out in accordance with the teacher's instructions;*
- *policy of deadlines and rescheduling: if a student did not pass or did not appear at the MKR (without a valid reason), his result is evaluated at 0 points. Recompilation of MKR results is not provided for;*
- *policy on academic integrity: the Code of Honor of the National Technical University of Ukraine "Kyiv Polytechnic Institute" https://kpi.ua/files/honorcode.pdf establishes general moral principles, rules of ethical behavior of individuals and provides a policy of academic integrity for persons working and studying at the university, which they should be guided by in their activities, including when preparing control measures in the discipline "Theory of automatic control";*
- *when using digital means of communication with the teacher (mobile communication, e-mail, correspondence on forums and social networks, etc.), it is necessary to observe generally accepted ethical norms, in particular, to be polite and limit communication to the working hours of the teacher.*

## 8. Types of control and rating system for evaluating learning outcomes (RSO)

***Current control*** *: work in lectures, practical and laboratory classes and MKR.*

***Calendar control*** *: is carried out twice a semester as a monitoring of the current state of meeting the requirements of the syllabus .*

***Semester control:*** *exam.*

*overall rating grade* ***R*** *consists of points received for: work in lectures and practical classes, for laboratory work, MKR (a modular control work is divided into two parts) and the exam.*

| Lecture classes | Practical classes | Computer workshop | Laboratory work | MKR | RGR | Exam |
|---|---|---|---|---|---|---|
| 9 | 9 | 18 | 12 | 6 | 10 | 36 |

### *System of rating points and evaluation criteria*

#### *Lecture classes*

*The weight factor is equal to 0.2. The maximum number of points for all 45 lectures is 0.2×45=9 points. Up to two weeks after the class is given to study the lecture.*

*Evaluation criteria*

*- the lecture is worked out by at least 60% 0.12...0.2*
*- less than 60% of the lecture has been processed*

#### *Practical classes*

*The weighting factor is equal to 1. The maximum number of points for all 9 practical works is 1×9=9 points. Practical tasks are given up to two weeks after the class.*

*Evaluation criteria*

*- performance of at least 60% of practical tasks 0.6...1*
*- completion of less than 60% of practical tasks 0*
*- incentive for activity in class 0.5*

#### *Computer workshop*

*The weighting factor is equal to 2. The maximum number of points for all 9 practical works is 2×9=18 points. Practical tasks are given up to two weeks after the class.*

*Evaluation criteria*

*- performance of at least 60% of practical tasks 1,2...2*
*- completion of less than 60% of practical tasks 0*
*- incentive for activity in class 0.2*

#### *Laboratory work*

*The weighting factor is equal to 3. The maximum number of points for 4 four-hour laboratory works is 3 ×4=12 points. A deadline of up to two weeks after the class is given for the preparation of a report on laboratory work. The defense of the report accepted by the teacher takes place no later than three weeks after the class.*

*Evaluation criteria*

*- full answer (at least 90% of the required information) 2,7...3*
*- sufficiently complete answer (at least 75% of the required information) 2.2...2.6*
*- incomplete answer (at least 60% of the required information) 1.8...2.1*
*- unsatisfactory answer (less than 60% of the required information) 0*
*-fine for untimely protection of laboratory work 0.5...1*

#### *Modular control work*

*The weighting factor is equal to 6. The maximum number of points for one MKR is 6×1=6 points. MKR is held no later than three weeks before the exam.*

*Evaluation criteria*

*- full answer (at least 90% of the required information) 5,4...6*
*- sufficiently complete answer (at least 75% of the required information) 4.5...5.3*
*- incomplete answer (at least 60% of the required information) 3.6...4.4*
*- unsatisfactory answer (less than 60% of the required information) 0*
*- absence without good reason 0*

***Calculation and graphic work***

*The weight factor is equal to 10. The maximum number of points for one calculation and graphic work is 10×1=10 points. The defense of the RGR takes place no later than two weeks before the exam.*

*Evaluation criteria*

*- complete answer (at least 90% of the required information) 9.. 10*
*- sufficiently complete answer (at least 75% of the required information) 7.5...8.9*
*- incomplete answer (at least 60% of the required information) 6... 7.4*
*- unsatisfactory answer (less than 60% of the required information) 0*
*-penalty for untimely protection of the RGR 1...2*

***Exam***

*The weighting factor is equal to 36. The maximum number of points for the answers on the exam is 36×1=36 points.*

*Evaluation criteria*

*- excellent answer (at least 90% of the required information) 32...36*
*- a good answer (at least 75% of the required information) 27...31*
*- a satisfactory answer (at least 60% of the required information) 2 2 ... 26*
*- unsatisfactory answer (less than 60% of the required information) 0*

*The examination ticket consists of two theoretical questions and one task. The maximum score for each theoretical question is 9 points, and for the problem - 18 points.*

***A condition for a positive intermediate certification** is a student's rating 50% lower than the maximum possible at the time of the certification.*

***The condition for admission to the exam** is the enrollment of all laboratory work and calculation and graphic work, as well as a starting rating of not less than 50% of the sum of points received in the semester, i.e. not less than 32 points, of which 21.2 points were received in Part I, and 10.8 points - in part II of the discipline.*

*Table of correspondence of rating points to grades on the university scale:*

| ***Overall R rating (sum of points)*** | ***Rating*** |
|---|---|
| *95...100* | *Perfectly* |
| *85...94* | *Very good* |
| *75...84* | *Good* |
| *65...74* | *Satisfactorily* |
| *60...64* | *Enough* |
| *Less than 60* | *Unsatisfactorily* |
| *Failure to meet the conditions for admission to the exam* | *Not allowed* |

## 9. Additional information on the discipline (educational component)

***A list of topics from Part I of the credit module that are submitted for semester control***

1. *General concepts and terms.*
2. *Classification of automatic devices. Advantages of automation.*
3. *A brief history of the development of automation.*
4. *Cybernetics, its main tasks and features.*
5. *Automatic control system (ACS) and its elements. Functional scheme .*
6. *SAC with feedback. Types of feedback.*
7. *Principles of automatic control.*
8. *Combined SAC. The main contradiction between statics and dynamics of SAC.*
9. *Informative principle of SAC classification. The main types of SAC.*
10. *Mathematical models of systems based on differential equations in ordinary and operator form.*
11. *Description of systems using transfer functions .*
12. *Structural schemes of SAC and rules for their transformation.*
13. *Transfer functions of SAC by external actions.*
14. *Forms of recording transfer functions.*
15. *The concept of the method of state variables. Vector-matrix equations of the SAC state.*
16. *Obtaining the state equations of the system by the transfer function.*
17. *Obtaining the state equations of the system according to the structural diagram.*
18. *Determination of transfer functions by state equations.*
19. *Controllability and observability of linear systems.*
20. *transformations and canonical forms of state equations.*
21. *Methods of solving state equations.*
22. *Structural transformations of SAC models in the state space.*
23. *Statics and dynamics of SAC.*
24. *Forms of recording dynamics equations on the example of a link R - L .*
25. *Linearization of mathematical models.*
26. *Aperiodic 1st order and integral links (equations of dynamics, transfer function, time characteristics).*
27. *Differential and inertial-differential links (equations of dynamics, transfer function, time characteristics).*
28. *Forcing and inertial- forcing links (equations of dynamics, transfer function, time characteristics).*
29. *Aperiodic link of the 2nd order (equation of dynamics, transfer function, time characteristics).*
30. *Oscillating link of the 2nd order (equation of dynamics, transfer function, time characteristics).*
31. *Delay link (equation of dynamics, transfer function, time characteristics).*
32. *Frequency characteristics of SAH.*
33. *Experimental method of construction of amplitude-phase frequency characteristics.*
34. *Logarithmic frequency characteristics.*
35. *Amplitude-phase frequency characteristics of typical links.*
36. *Logarithmic amplitude and phase frequency characteristics of typical links.*
37. *Minimally and non-minimally phase links. Their frequency characteristics.*
38. *Structurally unstable SAC.*
39. *The equation of the dynamics of the trail (program) SAC.*
40. *The dynamics equation of SAC stabilization.*

41. *Stability of linear systems. Lyapunov theorems.*
42. *Analysis of the stability of SAH by the roots of the characteristic equation.*
43. *The Raus -Hurwitz stability criterion .*
44. *Ljenar-Schipar stability criterion .*
45. *Obtaining critical values of parameters according to algebraic stability criteria.*
46. *Nyquist stability criterion in persistent open SAH. Resilience stocks.*
47. *Nyquist stability criterion in unstable open SAH.*
48. *Nyquist stability criterion in logarithmic form. Finding reserves of stability.*
49. *SAC quality. The main indicators of the quality of control in statics and dynamics.*
50. *The main ways of improving the quality of SAC.*
51. *Root methods of analysis of the quality of SAR.*
52. *Integral methods of management quality assessment.*
53. *Frequent methods of assessing the quality of SAC.*
54. *Introduction to the system of astatism of various orders. Isodromic integral link.*
55. *Control laws and typical regulators.*
56. *Proportional control law and P-regulators, advantages and disadvantages. The nature of the influence on static and dynamic characteristics.*
57. *Integral control law, its features. I-regulators, advantages and disadvantages.*
58. *Differential control law. D-regulators, their advantages and disadvantages.*
59. *Proportional-integral control law. PI regulators, their advantages and disadvantages.*
60. *Proportional-differential control law. PD regulators, advantages and disadvantages.*
61. *Proportional-integral-differential control law. PID regulators, their features.*
62. *Static and dynamic errors in SAC.*
63. *Typical operating modes of SAC.*
64. *Assessment of the accuracy of SAC using the method of error coefficients.*
65. *The accuracy of SAC when the external action changes at a constant speed.*
66. *The accuracy of SAC when changing the external action with constant acceleration.*
67. *Synthesis of SAC by the method of logarithmic amplitude frequency characteristics.*
68. *The principles of building the desired LAX according to the necessary indicators of management quality.*
69. *Synthesis of automatic systems by the method of modal control.*
70. *Standard characteristic polynomials of modal SACs.*

***A list of topics from part II of the credit module, which are submitted for semester control***

1. *package file system and kernel tools*
2. *Work table. Main windows and their purpose*
3. *Data types, reserved constants*
4. *Elementary functions*
5. *Formation of matrices and vectors, manipulation with them*
6. *Special vectors and matrices*
7. *The difference between element-by-element and matrix mathematical operations*
8. *Determination of array sizes*
9. *Basic functions of mathematical analysis*
10. *Construction of two-dimensional graphs in Cartesian coordinates*
11. *Management of types and colors of lines and markers*
12. *Applying textual information to graphics*
13. *Scaling of coordinate axes*
14. *Management of graphic windows and their arrangement*

15. *Programming of branched processes. Relational operations. Logical operations and functions.*
16. *Programming cycles with a known number of repetitions*
17. *Programming iterative cycles*
18. *Organization of the menu*
19. *Script files and function files*
20. *Linear algebra operations: calculation of determinants, minors and algebraic complements of matrices; inversion and transposition of matrices; solving systems of linear equations*
21. *Calculation of stable processes in branched linear electric circuits*
22. *Operations on power polynomials*
23. *Application of operations on power polynomials in solving problems in the theory of automatic control*
24. *Basic symbolic operations and functions in MATLAB*
25. *Construction of transient and weight characteristics*
26. *Construction of the response of SAC to linear influence. Determination of Q-factor by speed*
27. *Construction of zero-pole location maps of linear dynamic systems. Determination of their parameters.*
28. *Calculation and construction of frequency characteristics*
29. *Determination of stability reserves according to Bode and Nyquist diagrams*
30. *Approximation and interpolation in MATLAB*
31. *Numerical integration*
32. *Numerical methods of solving differential equations*
33. *Solving transcendental and algebraic equations*
34. *Solving systems of nonlinear equations in MATLAB*

***Certificates of completion of distance or online courses on the relevant subject may be credited subject to the fulfillment of the requirements specified in*** *ORDER NO. 7-177 DATED 01.10.2020 ON APPROVAL OF THE REGULATION ON RECOGNITION IN KPI NAMED AFTER IGOR SIKORSKYI OF LEARNING OUTCOMES ACQUIRED IN NON-FORMAL / INFORMAL EDUCATION*

**The working program of the educational discipline (syllabus) was compiled by:**

associate professor of the department of automation of electromechanical systems and electric drive FEA,
Ph.D. Priymak B.I.
and professor of the Department of Automation of Electromechanical Systems and Electric Drives of the FEA,
Ph.D. Tolochko O.I.

**Approved by** the Department of Automation of Electromechanical Systems and Electric Drives of the FEA (Protocol No. 15 of June 13, 2024)

**Agreed by** the Methodical Commission of the faculty (protocol No. 10 of June 20, 2024)