National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Department of Automation of Electrical and Mechatronic Complexes

SIMULATION OF MECHATRONIC SYSTEMS

Work program of the discipline (Syllabus)

Details of the discipline

Level of higher education	***First (bachelor's)***
Field of knowledge	*14 Electrical Engineering*
Speciality	*141 Electric Power Engineering, Electrical Engineering and Electromechanics*
Educational program	*Engineering of Intelligent Electrical and Mechatronic Complexes*
Discipline status	*Custom*
Form of study	*Full-time (full-time)/part-time/remote/*
Year of preparation, semester	*3rd year, spring semester*
Scope of discipline	*4.0 credits / 120 years*
Semester control / control measures	*Passed*
Timetable	*http://roz.kpi.ua/*
Language of instruction	*Ukrainian*
Information about Course Leader / Instructors	Lecturer: *Ph.D., Associate Professor Danilin Oleksandr Valeriyovych; e-mail: avdan@ukr.net; mеn. +38-067-907-91-19 (09:00 – 18:00)* Practical / Laboratory: *Ph.D., Associate Professor Danilin Oleksandr Valeriyovych; e-mail: avdan@ukr.net; mеn. +38-067-907-91-19 (10:00 – 18:00)*
Course Placement	Available on the Sikorsky platform. Google Classroom. The access code is provided by the teacher in the first lesson.

The program of the discipline

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

One of the important problems of engineering is the development of research methods for modern mechatronic systems and, on their basis, the creation of automated complexes and their control systems. When solving these problems, great importance is paid to *modeling*. In general, the modeling process can be represented as the study of some physical processes in the form of interrelated stages, each of which performs certain actions aimed at building and further use of information and logical models of systems. A characteristic feature of this process is its cyclic or interactive nature, which reflects modern requirements for the analysis and synthesis of complex automatic control systems.

The purpose of studying the discipline is to form the student's theoretical and practical knowledge, build mathematical models of mechatronic systems of varying complexity and create effective control algorithms for their study in practice.

Program learning outcomes: (K11) ability to solve practical problems using computer-aided design and calculation (CAD) systems; (K19) Awareness of the need to improve the efficiency of electric power, electrical and electromechanical equipment; (K22) Ability to provide simulation of electrotechnical and electromechanical objects and technological processes of production using standard packages and means of automation of engineering calculations, to conduct experiments according to specified methods with processing and analysis of results; (K25) Ability to apply the methods of the theory of automatic control, system analysis and numerical methods for the development of mathematical models of electrical and mechatronic complexes, analysis of the quality of their functioning using the latest computer technologies; (PR06) Apply application software, microcontrollers and microprocessor

technology to solve practical problems in professional activities; (PR08) select and apply suitable methods for the analysis and synthesis of electromechanical and electropower systems with specified indicators; (PR17) Solve complex specialized problems in the design and maintenance of electromechanical systems, electrical equipment of power plants, substations, systems and networks; (PRN22) To create universal and most effective algorithms for modeling the processes of electrical and mechatronic systems and to conduct their research on modern equipment with modern software.

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

The academic discipline "Modeling of Mechatronic Systems" is taught on the basis of knowledge and skills gained by students during the study of credit modules of such disciplines as: "Physics", "Higher Mathematics", "Theoretical Foundations of Electrical Engineering", "Theory of Automatic Control", "Computer Science and Programming", etc.

The knowledge and skills obtained in the process of studying the credit module "Modeling of Mechatronic Systems" are necessary for every specialist of the electrical engineering profile, who solve engineering problems in the field of electrical engineering and in the study of the following disciplines: "Electric Drive", "Automated Electric Drive of Machines and Installations", "Computer Modeling of Processes in Electrical Systems", "Intelligent Automatic Control Systems", etc.

3. The content of the discipline

Chapter 1. Basic provisions of the discipline. General Structure of Electrical Systems

Topic 1.1. Basic concepts and basic provisions

Topic 1.2. Synthesis of Mathematical Models of Electrical Systems

Chapter 2. Laplace transform and its properties

Topic 2.1. Laplace transformation. Original & Image

Topic 2.2. Properties. Laplace-Carson transformation

Chapter 3. Methods for solving differential equations

Topic 3.1. Numerical Integration

Topic 3.2. Approximation of functions

Chapter 4. Implementation of mathematical models of mechatronic systems

Topic 4.1. Non-linear elements

Topic 4.2. Block diagrams of research algorithms

4. Training Materials & Resources

Basic

5. Modeling of electromechanical processes and systems. Helps. / O.V. Danilin, V.M. Chermalikh, P.V. Rosen. – K.: NTUU "KPI", 2007. – 52 p.

6. Shchokin V.P. Modeling of electromechanical systems: textbook / V.P. Shchokin [and others]. - Kyiv: Kondor, 2018. - 203 p.

7. Using the MATLAB–Simulink Package to Model Dynamical Systems and Devices: Method. Instructions for the performance of laboratory, calculation and graphic work, course and diploma design for students. Special. 7.092203 – "Electromechanical Automation Systems and Electric Drive" and 7.092204 – "Electromechanical Equipment of Energy-Intensive Industries" / Compilers: O.V. Chermalikh, O.V. Danilin, V.V. Kuznetsov. Kyiv: Polytechnic Publishing House, 2004. – 72 p.

Secondary

8. Lozynskyi A.O., Moroz V.I., Paranchuk Y.S. Solving electromechanics problems in the environments of MathCAD and MATLAB packages: Textbook. – Lviv: Lviv Polytechnic State University Press, 2000. – 166 p.

9. Kozbur I.R. Modeling of control systems in the MATLAB SIMULINK package, methodical instructions for laboratory work on the course "Computer methods of research of automatic control

systems", for 4th year students of the specialty 6.050201 "System Engineering" / incl. : I.R. Kozbur, G.V. Kozbur, R.I. Mykhailyshyn. Ternopil: TNTU, 2019. - 23 p. http://elartu.tntu.edu.ua/handle/lib/28056

10. Modeling of electrical and mechatronic systems. Educational edition [Electronic resource] : tutorial for bachelor's degree programs for an educational program "Engineering of Intelligent Electrotechnical and Mechatronic Complexes" / O. V. Danilin, A. V. Bosak, V. O. Bronytskyi, L. V. Toropova ; Igor Sikorsky Kiev Polytechnic Institute. – Electronic text data (1 file: 1,27 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2021. – 55 p. https://ela.kpi.ua/handle/123456789/47291

11. Gogoliuk, P. F. Teoriya avtomatnoho upravlinnia [Theory of automatic control]. Helps. / P.F. Gogolyuk, T.M. Grechin; Ministry of Education and Science, Youth and Sports of Ukraine, Nats. Lviv Polytechnic University. - Lviv: Lviv Polytechnic Publishing House, 2012. - 279 p.

References, the bibliography of which is given with a link, can be found on the Internet. Literature, the bibliography of which does not contain references, can be found in the library of Igor Sikorsky Kyiv Polytechnic Institute. Igor Sikorsky.

Separate sections of basic literature [1]-[3] are required reading. Sections of basic literature that are mandatory reading, as well as the connection of these resources with specific topics of the discipline, are given below, in the methodology of mastering the discipline. All other literary sources are optional, it is recommended to read them

Educational content

5. Methods of mastering the discipline (educational component)

The general methodical approach to teaching the discipline is defined as communicative-cognitive and professionally oriented, according to which the student – the subject of learning – is at the center of the educational process. The methodology of teaching the discipline combines visual teaching methods with explanation. Teaching is carried out in the form of lectures, practical and laboratory classes in the form of a computer workshop.

Lectures

Salary No.	Title of the topic of the lecture and a list of the main issues (links to literature)
1	**Title of the lecture topic:** Introduction to the discipline **List of main issues:** Basic concepts of modeling (physical and mathematical modeling, object-oriented principle, system, process, parameters, properties, state, characteristics, etc.). **References:** [2, 4]
2	**Lecture topic:** Simulation, object-oriented modeling **List of main issues:** Methods of constructing a simulation model. Block diagram of a generalized electromechanical system. The main blocks and modules of the system. Vector-matrix model of ETS. Deterministic and non-deterministic models. Mathematical model of the "black box" **References:** [1, 7]
3	**Title of the lecture topic:** Construction of mathematical models of technical systems. Hydraulic Actuator **List of main issues:** Hydraulic drive. Obtaining differential equations of systems, block diagrams and transfer functions. **References:** [1, 6]

4	**Title of the lecture topic:** Construction of mathematical models of technical systems. Independent Excitation DC Electric Motor **List of main issues:** Independent excitation DC electric motor. Obtaining differential equations of systems, block diagrams and transfer functions. **References:** [1, 6]
5	**Title of the lecture topic:** Construction of mathematical models of technical systems. Resilient Mechanical System **List of main issues:** Elastic mechanical system. Obtaining differential equations of systems, structural diagrams and transfer functions. **References:** [1, 6]
6	**Title of the lecture topic:** Construction of mathematical models of technical systems. Electrical circuit with inductor, resistor and capacitor **List of main issues:** An electrical circuit with an inductor, a resistor, and a capacitor. Obtaining differential equations of systems, block diagrams and transfer functions. **References:** [1, 6]
7	**Title of the topic of the lesson:** Laplace transformation. Basic concepts. **List of main issues:** The concept of the original and the image. Direct and inverse Laplace transform. Geometrical essence of the convergence of the integral. **References:** [3, 6]
8	**Title of the topic of the lesson:** Basic properties of the Laplace transform **List of main issues:** Homogeneity, additivity, similarity theorem, displacement theorem, differentiation of original and image **References:** [3, 6]
9	**Class topic title:** Laplace-Carson transformation **List of main issues:** Direct and reverse conversion. Main properties and scope of application. **References:** [3, 6]
10	**Title of the lesson:** General Method of Solving Differential Equations **List of main issues:** Mathematical essence of the operator method. **References:** [3, 7]
11	**Title of the lesson:** General Method of Solving Differential Equations **List of main questions:** Mathematical essence of the first-order Runge-Kutta method. **References:** [3, 7]
12	**Title of the lecture topic:** Numerical integration **List of main issues: The** concept of an approximating function. The problem of interpolation and approximation of a function. Numerical Integration of Differential Equations **References:** [1, 4]
13	**Title of the lecture topic:** Stepwise approximation of functions. **List of main issues: Approximation function.** The problem of interpolation and approximation of a function. Approximation methods. Stepwise Approximation of Functions **References:** [1, 4]
14	**Title of the lecture topic:** Stepwise approximation of functions in advance. **List of main issues:** Approximation function. The problem of interpolation and approximation of a function. Approximation methods. Stepwise anticipatory approximation of functions **References:** [1, 4]

15	**Title of the lecture topic:** Piecewise linear approximation of functions. **List of main issues:** Approximation function. The problem of interpolation and approximation of a function. Approximation methods. Piecewise linear approximation of functions **References:** [1, 4]
16	**Title of the lecture topic:** Implementation of nonlinear elements of the relay type. **List of main issues:** Analytical description and construction of block diagrams of algorithms of elements of the "relay" type Using the MATLAB environment for interactive modeling of nonlinear elements **References:** [2, 6].
17	**Title of the lecture topic:** Implementation of nonlinear elements with a hysteresis loop. **List of main issues:** Analytical description and construction of block diagrams of algorithms of elements with a "hysteresis loop". Using the MATLAB Environment for Interactive Modeling of Nonlinear Elements **References:** [2, 6].
18	**Title of the lecture topic:** Implementation of the differentiation operation. **List of main issues:** Using the MATLAB environment for interactive simulation of the differentiation operation. **References:** [1, 3].

Practical classes (computer workshop)

The main task of the cycle of practical classes is to consolidate the theoretical provisions of the discipline and acquire the ability to apply them in practice by performing certain appropriately formulated tasks with the help of special computer programs.

Salary No.	Name of the topic of practical classes (computer practicum) and a list of the main questions (references to literature)
1	**Title of the lesson:** Solving a second-order differential equation with a special right-hand side under non-zero initial conditions by the numerical-analytical method according to a detailed method **List of main issues:** To make a block diagram of the algorithm for the functioning of a digital model of a differential equation by the numerical-analytical method according to a detailed method **References:** [1, 3]
2	**Title of the lesson:** Solving a second-order differential equation with a special right-hand side under non-zero initial conditions by the numerical-analytical method according to the generalized method **List of main issues:** To draw up a block diagram of the algorithm for the functioning of a digital model of a differential equation by the numerical-analytical method according to the generalized method **References:** [2, 3]
3	**Title of the lesson:** Solving a second-order differential equation with a special right-hand side under non-zero initial conditions by the numerical-analytical method according to a detailed method **List of main issues:** To synthesize a SIMULINK model of a differential equation in the MATLAB environment and obtain graphical results of computer modeling by the numerical-analytical method according to a detailed method

	References: [1, 3]
4	**Title of the lesson:** Solving a second-order differential equation with a special right-hand side under non-zero initial conditions by the numerical-analytical method according to the generalized method **List of main issues:** To synthesize the SIMULINK model of the differential equation in the MATLAB environment and to obtain graphical results of computer modeling by the numerical-analytical method according to the generalized method **References:** [2, 3]
5	**Title of the lesson:** Solving a second-order differential equation with a special right-hand side under non-zero initial conditions by the *Z-transform method according to a detailed method* **List of main issues:** To make a block diagram of the algorithm for the functioning of a digital model of a differential equation using the *Z-transform method according to a detailed method* **References:** [2, 4]
6	**Title of the lesson:** Solving a second-order differential equation with a special right-hand side under non-zero initial conditions by *the Z-transform* method **List of main issues:** To make a block diagram of the algorithm for the functioning of a digital model of a differential equation by the *Z-transform method according to the generalized method* **References:** [1, 5]
7	**Title of the lesson:** Solving a second-order differential equation with a special right-hand side under non-zero initial conditions by the *Z-transform method according to a detailed method* **List of main issues:** To synthesize a SIMULINK model of a differential equation in the MATLAB environment and obtain graphical results of computer modeling by *the* Z-transform method according to a detailed method **References:** [2, 4]
8	**Title of the lesson:** Solving a second-order differential equation with a special right-hand side with non-zero initial Z-transform method using the generalized method **List of main issues:** To synthesize the SIMULINK model of the differential equation in the MATLAB environment and to obtain graphical results of computer modeling by the *Z-transform method according to the generalized method* **References:** [1, 5]
9	**Passed**

Laboratory classes

The main task of the cycle of laboratory classes is to conduct simulation experiments on a computer in order to form skills and abilities of practical confirmation of certain theoretical provisions, mastering the methodology of experimental research and processing of the data obtained.

Salary No.	**Lab Topic Title and a list of the main questions (references to literature)**
1	**Title of the lesson:** Synthesis of mathematical models of technical systems of different physical nature (hydraulic drive) **List of main issues:** Preparation of an analytical description, differential equations and a block diagram of a hydraulic drive system **References:** [2, 5]

2	**Title of the lesson:** Synthesis of mathematical models of technical systems of different physical nature (DC electric motor) **List of main issues:** Preparation of an analytical description, differential equations and a block diagram of a DC electric motor system **References:** [1, 4]
3	**Title of the lesson:** Synthesis of mathematical models of technical systems of different physical nature (elastic mechanical system) **List of main issues:** Compilation of an analytical description, differential equations and a block diagram of an elastic mechanical system **References:** [3, 4]
4	**Title of the lesson:** Synthesis of mathematical models of technical systems of different physical nature (electric circuit) **List of main issues:** Compilation of an analytical description, differential equations and a block diagram of an electric circuit **References:** [1, 4]
5	**Title of the lesson:** General Method of Solving Differential Equations **List of main issues:** Mathematical essence of the operator method and the Runge-Kutta method. **References:** [2, 4]
6	**Title of the topic of the lesson:** Numerical integration. Stepwise Approximation of Functions **List of main issues:** Geometrical essence of step approximation. Exposition of basic mathematical dependencies for second-order integrators. **References:** [1, 5]
7	**Title of the topic of the lesson:** Numerical integration. Stepwise anticipatory approximation of functions **List of main issues:** Geometrical essence of stepped approximation in advance. Statement of basic mathematical dependencies for second-order integrators. **References:** [1, 5]
8	**Title of the topic of the lesson:** Numerical integration. Piecewise linear approximation of functions **List of main issues:** Geometric essence of piecewise linear approximation. Exposition of basic mathematical dependencies for second-order integrators. **References:** [1, 5]
9	**Title of the lesson:** Implementation of nonlinear elements and differentiation operations. **List of main issues:** Compilation of analytical dependencies and block diagrams of the algorithm for the study of nonlinear elements of the relay type and the Hysteresis loop. Mathematical description of the differentiation operation. **References:** [2, 7]

6. Independent work of a student/graduate student

Independent work of the student according to the curriculum provides 66 hours:
preparation for classroom classes – 56 hours;
preparation for the modular test – 4 hours;
preparation for the test – 6 hours.

Policy & Control

7. Academic discipline policy (educational component)

At the time of each lesson, both lecture and practical, the student must have the Zoom application installed on the device from which he works (in the case of distance learning), as well as open the course "Modeling of mechatronic systems" on the Sikorsky platform (the access code to the course is provided at the first lesson according to the schedule). syllabus; lecture material; tasks for a computer workshop; options for modular tests; methodical recommendations for performance of computer practicum and calculation work; the list of theoretical questions and practical tasks for the test is posted on the Sikorsky platform and in the KPI Electronic Campus system.

During the course "Modeling of Mechatronic Systems", students are required to adhere to the general moral principles and rules of ethical behavior specified in the Code of Honor of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute".

The deadlines for each task are specified in the course "Modeling of mechatronic systems" on the Sikorsky platform.

All students, without exception, are obliged to comply with the requirements of the Regulations on the System for the Prevention of Academic Plagiarism at the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute".

8. Types of control and rating system for assessing learning outcomes (CRO)

1. The student's rating in the credit module is calculated from 100 points, of which:

- 8 tasks of the computer workshop;
- performing tasks in 9 laboratory classes;
- two modular tests (one modular test is divided into two tests lasting one academic hour each);

2. Criteria for awarding points:

2.1. Computer workshops:

The weight score is 5. Maximum number of points: 5 × points 8 points. = 40 points.

Criteria for evaluating the performance of the tasks of the computer workshop	**Points**
Complete exhaustive fulfillment (at least 90%)	4… 5
Full performance with some flaws (at least 75%)	3
Incomplete implementation with significant deficiencies (at least 60%)	2
Rather weak or incorrect performance (less than 60%)	0

2.2. Laboratory classes

The weight score is 4. Maximum number of points: 4 × points 9 points. = 36 points.

Criteria for evaluating the performance of laboratory tasks	**Points**
Complete exhaustive fulfillment (at least 90%)	4
Full performance with some flaws (at least 75%)	3
Incomplete implementation with significant deficiencies (at least 60%)	2
Rather weak or incorrect performance (less than 60%)	0

2.3. Modular control

The weight score is 14. Maximum number of points: 12 points × 2 work. = 24 points.

Criteria for assessing the implementation of the ICR	Points
Complete answer (at least 90% of the required information)	10… 12
a sufficiently complete answer (at least 75% of the required information), or a complete answer with minor inaccuracies	6… 9
incomplete answer (at least 60% of the required information) and minor errors	2… 5
Unsatisfactory response (does not meet the requirements for "satisfactory")	0… 1

For participation in the All-Ukrainian Olympiad (competition of scientific papers) the student is awarded 5 (I round) or 10 (II round) points. For writing an article and its publication, a student is awarded 10 points (a publication included in Scopus or Web of Science) or 6 points (a professional publication of Ukraine). For the publication of abstracts at a scientific conference – 3 points. The total amount of incentive points cannot exceed 10 points.

3. Calendar control.

Calendar control is carried out twice a semester as a monitoring of the current state of implementation of the requirements of the syllabus. The condition for a positive first and second calendar control is to obtain at least 50% of the maximum possible rating at the time of the relevant calendar control.

4. Semester control.

Semester control: Credit.

Conditions for admission to semester control: fulfillment of all tasks of computer practicum and laboratory work, as well as implementation of modular tests.

RSmax: 40 + 36 + 24 = 100 points.

RSmin: 10 + 8 + 12 = 30 points.

Students who have fulfilled all the conditions for admission to the test and have a rating score of 60 or more points receive a grade corresponding to the scored rating without additional tests. The sum of the rating points received by the student during the semester is transferred to the final grade according to the table.

If the sum of points is less than 60, but all computer workshops, laboratory work, MCR are completed and credited, the student performs a test work. In this case, the sum of points for computer workshops, laboratory work, MKR and test work is transferred to the final grade according to the table.

A student who received more than 60 points in the semester, but wants to improve his result, can also do credit work. In this case, the final result consists of the points received for the test work, and the points for computer workshops, laboratory work, MCR.

The test work is estimated at 40 points. The control task of this work consists of one theoretical question from the list provided in the appendix to the syllabus, and a practical task.

Each theoretical question and task is worth 20 points according to the following criteria:

Theoretical Question Grading System	Points
"excellent", full answer (at least 90% of the required information)	16… 20
"good", a sufficiently complete answer (at least 75% of the required information or minor inaccuracies)	10… 15
"satisfactory", incomplete answer (at least 60% of the required information and some errors)	6… 9
"unsatisfactory", unsatisfactory answer	0… 5

Practical Task Grading System	Points
"excellent", complete error-free solution of the problem	16… 20
"good", complete solution of the problem with minor inaccuracies	10… 15

"satisfactory", the task was completed with certain shortcomings	6… 9
"unsatisfactory", the task was not completed	0… 5

For part-time study.

Current control: MCR (conducted directly at the lecture in the presence of the teacher, 24 points); computer workshops (40 points), laboratory work (36 points). The structure of the MCR, the requirements for them and the evaluation criteria are similar to those for full-time education and are given above.

The sum of the points received during the academic semester and points for the test work (if necessary) is transferred to the final grade according to the table:

Rating points	**University Scale Score**
95… 100	Perfectly
85… 94	very good
75… 84	well
65… 74	Satisfactory
60… 64	enough
Less than 60	Disappointing
Failure to comply with the conditions of admission to the test	Not allowed

9. Additional information on the discipline (educational component)

The list of questions that are submitted for semester control is given in the appendix to the syllabus. A higher education applicant has the opportunity to take an online course(s) on one or more topics provided for by the curriculum of the discipline. The applicant can choose an online course independently or on the recommendation of a teacher, on the Coursera or Udemy platform. 1 hour of the course is estimated at 0.83 points. The maximum number of hours that can be counted based on the results of non-formal education is 12 hours, respectively, the maximum number of points for such results is 10 points.

TEST QUESTIONS:

1. To reveal the basic concepts of modeling (physical and mathematical modeling, object-oriented principle, system, process, parameters, properties, state, characteristics, etc.).
2. To reveal the basic concepts of modeling (deterministic and non-deterministic models, simulation modeling, mathematical model of the "black box") and to reflect the general structure of the electrical system.
3. Compose a differential equation, a transfer function and build a block diagram of a hydraulic drive system.
4. Compose a differential equation, a transfer function and build a block diagram of a DC electric motor system of independent excitation.
5. To compose differential equations and transfer functions of an elastic mechanical system.
6. Compose differential equations and transfer functions of an electric circuit.

7. Display the mathematical essence of the Laplace transform (original and image). The geometrical essence of the convergence of the integral.

8. Display the basic properties of the Laplace transform. Homogeneity, additivity, similarity theorem, displacement theorem, differentiation of the original and the image.

9. Display the basic properties of the Laplace transform. Integration of the original and the image, the lag theorem, the image convolution theorem, the Duhamel integral, the Delta function.

10. To reflect the mathematical essence of the Laplace-Carson transform and to give the basic formulas of the transformation.

11. To give a general method for solving differential equations and to state the main provisions of the operator method.

12. To formulate a general method for solving differential equations and to present the main provisions of the first-order Runge-Kutta method.

13. Formulate the basic concepts of numerical integration and compose mathematical equations of a linear system of four integrating elements.

14. To state the mathematical essence of the approximation of functions: stepped and stepped approximation with bias.

15. To present the mathematical essence of the approximation of functions: piecewise linear approximation and Lagrange polynomial.

16. To prove the geometric essence of the differentiation operation and implement it using a numerical equation and Z-transformation.

17. To present the methodology for the implementation of nonlinear elements and to draw up an analytical description and block diagrams of algorithms for the implementation of nonlinear elements with a relay characteristic.

18. To present the methodology for the implementation of nonlinear elements and to draw up an analytical description and block diagram of the algorithm for the implementation of a nonlinear element with a hysteresis loop.

Work program of the discipline (syllabus):

Compiled by: Associate Professor of the AEMC Department, Ph.D.,
Associate **Professor Danilin Oleksandr Valeriiovych**

Approved by: AEMC Department (Minutes No. 17 dated 31.05.2023)

Approved by: Methodological Commission of the IEE (Minutes No. 9 dated 22.06.2023).)