Національний технічний університет України
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

Department of Electromechanical Systems Automation and Electrical Drives
FEA

OPTIMAL AND INTELLLGENT CONTROL SYSTEMS

Work program of the discipline (Syllabus)

Details of the discipline

Level of higher education	***Second (master's)***
Branch of knowledge	*14 "Electrical Engineering"*
Specialty	*141 "Electric power, electrical engineering and electromechanics"*
Educational program	*Electromechanical automation systems, electric drive and electric mobility*
Discipline status	*Normative*
Form of study	*Full-time (day)*
Year of preparation, semester	*I course, spring semester*
The scope of discipline	*150 hours / 6 ECTS credits*
Semester control / control measures	*Offset / MCR*
Timetable	*http://rozklad.kpi.ua/Schedules/ViewSchedule.aspx?v=fcdd26a5-1e05-452c-bab5-0604b5d84a4f*
Language of instruction	*Ukrainian*
Information about the course leader / teachers	Lecturer: *Doctor of Technical Sciences, Professor, Tolochko Olga Ivanivna, tel. 0994945473* Practical training:*Doctor of Technical Sciences, Professor, Tolochko Olga Ivanivna, tel. 0994945473;*
Course placement	*Google Classroom https://classroom.google.com/c/ Mzc4NDkyNjMyNDU1*

Curriculum

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

The curriculum of the discipline "Optimal and intelligent Control Systems" is compiled in accordance with the educational-professional training program for masters in the field of knowledge 14 "Electrical Engineering" in specialty 141 "Electricity, electrical engineering and electromechanic" from the educational program "Electromechanical automation systems, electric drive and electric mobility".

The purpose of the discipline*"Optimal and intelligent control systems" is the formation of students' ability to solve problems of variational calculus; find the extrema of functions of one and several variables; apply methods for solving unconditional and conditional optimization problems to improve energy performance and quality indicators of transients in controlled electric drive systems; determine the necessary strategies for optimal control of the electric drive, based on the technological conditions of their operation.*

The subject of the discipline *- variational calculus; Euler, Euler-Poisson, Lagrange methods; the Pontryagin maximum principle; strategies for optimal control of the electric drive; synthesis of energy-optimal systems (minimization of certain types of losses, maximization of electric drive efficiency); synthesis of electric drive systems that are optimal in terms of speed.*

Program learning outcomes:

Competencies:(LC1) the ability to search, process and analyze information from various sources; (LC2) the ability to use information and communication technologies; (LC5) the ability to make *informed decisions; (LC6) the ability to learn and master modern knowledge; (FC4) the ability to demonstrate knowledge and understanding of mathematical principles and methods required for use in power engineering, electrical engineering and electromechanics; (FC9) the ability to use software for computer modeling, computer-aided design, automated production and automated development or design of elements of electrical, electrical and electromechanical systems; (FC11) ability to design robust and adaptive control algorithms for electromechanical automation systems and electric drives, develop optimal and intelligent control laws using identification and observation methods; (FC15) the ability to use software for computer modeling, computer-aided design, automated production and automated development or design of elements of electrical, electrical and electromechanical systems; (FC17) ability to perform research and development work involving the development of new and modernization of existing electromechanical automation systems and electric drives. automated production and automated development or design of elements of electric power, electrotechnical and electromechanical systems; (FC17) ability to perform research and development work involving the development of new and modernization of existing electromechanical automation systems and electric drives. automated production and automated development or design of elements of electric power, electrotechnical and electromechanical systems; (FC17) ability to perform research and development work involving the development of new and modernization of existing electromechanical automation systems and electric drives.*

Knowledge:(PH03) to analyze the processes in electrical, electrical and electromechanical equipment and relevant complexes and systems; (PH04) to reconstruct existing electrical networks, stations and substations, electrical and electromechanical complexes and systems in order to increase their reliability, operational efficiency and resource life; (PH05) to have methods of mathematical and physical modeling of objects and processes in electric power, electrotechnical and electromechanical systems; (PH09) to adhere to the principles and directions of the strategy of development of energy security of Ukraine; (PH10) to substantiate the choice of direction and methods of scientific research taking into account modern problems in the field of electric power, electrical engineering and electromechanics.

Skills:(PH01) to reproduce processes in electric power, electrotechnical and electromechanical systems at their computer modeling; (PH14) to master new versions or new software designed for computer modeling of objects and processes in electrical, electrical and electromechanical systems; (PH16) to design fuzzy regulators, neural networks, genetic algorithms, estimators of technological coordinates and parameters for electromechanical control systems of automatic and electric drives; (PH18) to develop intelligent automatic control systems, new control algorithms for dynamic systems, to perform digital signal processing in electromechanical systems; (PH19) to apply energy efficient control methods in the development of new electromechanical automation systems and electric drives, electric vehicles.

2. Prerequisites and postrequisites of the discipline (place in the structural and logical scheme of education according to the relevant educational program)

The discipline "Optimal and intelligent control systems" requires first of all knowledge of the disciplines "Theory of automatic control" and "Automated electric drive systems". The knowledge and skills acquired by students in the study of the discipline "Optimal and Intellectual Management" will be useful to them in the final master's thesis.

3. The content of the discipline

The discipline is structurally divided into 2 sections, namely:

***Introduction**, devoted to the history of optimal management and its individual areas with the addition of biographies of prominent scientists*

***Section 1. "Optimal control systems"**, which includes the definition of functionality and its main properties, solving problems at unconditional extremum, synthesis of optimal control of demagnetization and magnetization of a stationary vector-controlled induction motor, solving variational problems at conditional extremum, optimal control of positional drive systems with limitation or minimization of heat and synthesis of optimal control of flux coupling of the rotor of a vector-controlled induction motor from the conditions of minimizing stator current at a given* *moment and from the conditions of efficiency maximization, strategy of optimal control of torque and speed of synchronous motor with permanent magnets built into the rotor.*

4. Training materials and resources

<ins>*Main information resources:*</ins>

1. *Popovich MG, Kovalchuk OV Theory of automatic control. K .: Lybid. 2007. - 655 p.*
2. *Tolochko OI Optimal and intelligent control systems in electromechanical systems. Part 1. Optimal control in electromechanics. Workshop. [Electronic resource]: textbook. way. for students majoring in 141 "Power Engineering, Electrical Engineering and Electromechanics"; Kyiv: KPI named after Igor Sikorsky, 2019. - 117 p.*
3. *Zhaldak MI, Trius Yu.V. Fundamentals of theory and optimization methods. Tutorial. - Cherkasy: Brama-Ukraine, 2005. - 608 p.*

<ins>*Additional:*</ins>

4. *Zak SH Systems and Control. Oxford University Press, 2003. - 770 p.*
5. *Tolochko OI Modeling of electromechanical systems. Mathematical modeling of asynchronous electric drive systems: Textbook. - Kyiv: NTU "KPI" (electronic edition), 2016. - 150 p.*
6. *O.Tolochko. Energy Efficient Speed Control of Interior Permanent Magnet Synchronous Motor // Chapter in the free-open book "Applied Modern Control", ISBN 978-1-78984-827-4, DOI: 10.5772 / intechopen.80424, Published: February 13th 2019*

Educational content

5. Methods of mastering the discipline (educational component)

Lectures

№ s / n	*The title of the lecture topic and a list of key issues (list of teaching aids, links to information sources)*
1	***Introduction.*** *The purpose of the discipline. History and main directions of development of the theory of optimal control.* *Literature: [3], p. 9-19;* *CPC :. Elaboration of lecture material and recommended literature.*
2	***Section 1. OPTIMAL CONTROL SYSTEMS*** ***Topic 1. Basic concepts and definitions.*** *Functional and its main properties. Functional and its main properties. Statement and classification of optimal control problems. Optimality criteria.* *Literature: [1], p. 563-566; [3], p. 26-33.* *VTS: Development of lecture material and recommended literature.*
3	***Topic 2. Search for extrema of functions.*** *Classification of problems and methods for solving minimax problems. Unconstrained and constrained scalar bounded and multidimensional minimization.* *Literature: [3], p. 36-56.* *VTS: Development of lecture material and recommended literature.*
4	***Topic 3. Synthesis of the system of optimal control of flux coupling of the rotor of a vector-controlled induction motor (IM) from the conditions of minimizing the stator current at a given moment and from the conditions of efficiency maximization.*** *Classification of losses in blood pressure. Mathematical description of IM in the rotor reference frame. Statement of the optimization problem. Determination of energy performance of the electric drive. Synthesis and mathematical modelling of a typical optimal control system. Synthesis of the optimal control system. Comparative analysis of energy characteristics.* *Literature: [2], p. 19-32.* *CPC: Elaboration of lecture material and recommended literature.*

5	***Topic 4. The problem of unconstrained extremum.*** *Euler and Euler-Poisson equations. Derivation of Euler's equation for the simplest functional. Legendre's theorem. Some cases of Euler's method. Examples of application of the Euler method.* *Literature: [1], p. 566-569; [2], p. 34.* *VTS: Development of lecture material and recommended literature.*
6	***Topic 5. The problem of brachistochrony***. *Formulation of the problem. Solving the problem by Euler's method. Construction of optimal trajectories. Comparison of body movement time on optimal and linear trajectories.* *Literature: [2], p. 5-18.* *VTS: Development of lecture material and recommended literature.*
7	***Topic 6. Synthesis of optimal control of demagnetization and magnetization processes of a stationary vector-controlled induction motor.*** *Mathematical description of the flux control circuit of the rotor of a vector-controlled induction motor. Statement of the optimization problem. Compilation of Euler's equation and its solution. Determination of minimized losses. Search for optimal parameters of exponential and linear laws of rotor flux coupling control.* *Literature: [2], p. 34-52.* *VTS: Development of lecture material and recommended literature.*
8	***Topic 7. The problem of conditional extremum.*** *Formulation of the problem. Euler-Lagrange equation. Definitions of Lagrange and Hamiltonian. Examples of application of the Euler-Lagrange method.* *Literature: [1], p. 569-574; [2], p. 34.* *VTS: Development of lecture material and recommended literature.*
9	***Topic 8. Strategies for optimal control of torque and speed of a synchronous motor with permanent magnets built into the rotor.*** *Mathematical description of a vector-controlled synchronous motor with surface and built-in permanent magnets. Statement and solution of optimal control strategies "Maximum torque per ampere" and "Maximum torque per ampere". Structural ways to implement optimal strategies.* *Literature: [2], p. 53-64.* *VTS: Development of lecture material and recommended literature.*
10	***Topic 9. Optimal control of positional electric drive systems with limitation or minimization of heat losses.*** *Mathematical description of the position electric drive. Statement of optimal control problems: 1) energy-optimal - minimization of heat losses at a given movement and a given time of its operation; 2) terminal problem - the fastest movement with limited heat loss; 3) the maximum displacement for a given time with a limit on heat loss. Compilation of Euler-Lagrange equations and their solution. Statement of the quasi-optimal control problem with minimization of heat losses and its solution. Literature: [1], p. 572-575; [2], p. 65-78.* *VTS: Development of lecture material and recommended literature.*
11	***Topic 10. Non-classical variation calculus. Pontryagin's maximum principle.****The concept of the principle of maximum. Feldbaum's theorem on n intervals. Solution of the problem of synthesis of linear systems optimal for response speed.* *Literature: [1], p. 575-589; [2], p. 79-85.* *VTS: Development of lecture material and recommended literature.*
12	***Topic 11. Optimal speed control of positional electric drive systems.*** *Application of the maximum principle for the synthesis of optimal speed control of positional electric drive. Synthesis of the law of optimal control. Synthesis of a nonlinear position regulator. Structural synthesis of the position unit.* *Literature: [2], p. 86-91.* *VTS: Development of lecture material and recommended literature.*
13	***Topic 12. Optimal for the operation speed of the load oscillations suppression of the load suspended from the mechanism of translational motion.*** *Mathematical description of the oscillations of the load suspended from the mechanism of translational motion. The equation of*

	optimization of the motion of the mechanism of translational movement from the conditions of the fastest damping of oscillations of the load suspended to it. *Literature: [2], p. 92-109.* *VTS: Development of lecture material and recommended literature.*
14	***Topic 13. Basic concepts of dynamic Bellman programming and analytical design of regulators.*** *Literature: [1], p. 623-627.* *VTS: Development of lecture material and recommended literature.*

Practical training

№ s / n	*The name of the topic that is submitted for independent study*	*Number hours of CPC*
1	*Familiarity with the properties of epicycloids and brachystochrones*	*2*
2	*Solving the problem of the fastest descent*	*2*
3	*Optimal control of asynchronous electric drive according to the strategies "Maximum torque per ampere" and "Minimization of losses in copper"*	*3*
4	*Optimal laws of magnetization and demagnetization of a vector-controlled induction motor in pauses of repeated short-term operation.*	*2*
5	*Optimal control strategies for open-pole synchronous motors with permanent magnets*	*2*
6	*Synthesis and analysis of set point devices that implement optimal and quasi-optimal laws of control of positional drive in terms of heat loss*	*2*
7	*Synthesis and analysis of optimal speed of positional electric drive systems.*	*2*
8	*Optimal and quasi-optimal in terms of the speed of damping the oscillations of the mechanical system of the overhead travelling crane.*	*3*
	Total	***18***

Abstract

The abstract is based on the results of acquaintance with modern English (foreign) publications on the application of methods of the theory of optimal control in systems of adjustable electric drive. In the simplest version, the main part of the abstract consists of a translation of the basic publication into Ukrainian with all the formulas, figures and lists of references. The appendix contains the original article with reference to it. Proposed publications are provided by the teacher, but each student can choose an article or excerpt from a book, dissertation, etc. at their discretion after consultation with the teacher. It is desirable when choosing to consider the subject of their bachelor's and future master's theses.

During the preparation of abstracts students get acquainted with modern trends in the field of automated electric drive with optimal control, improve knowledge of English technical terminology, get acquainted with the rules of publication in peer-reviewed publications, prepare materials for analytical review of literature sources on future master's thesis. technical literature.

The content of abstracts is discussed in the penultimate lecture.

6. Independent work of student

№ s / n	*The name of the topic that is submitted for independent study*	*Number hours of CPC*
1	*Preparation of answers to control questions for lectures*	*10*

2	*Preparation of reports on practical classes*	*16*
3	*Preparation of the abstract*	*10*

Policy and control

7. Course policy (educational component)

The system of requirements that the teacher puts before the student:

- *rules of attendance: in accordance with Order 1-273 of 14.09.2020, it is prohibited to assess the presence or absence of the applicant in the classroom, including the accrual of incentive or penalty points. According to the RSO of this discipline, points are awarded for the relevant types of educational activity in lectures and practical classes. Practice of laboratory works on the discipline is a mandatory condition for admission to the test;*
- *rules of conduct in the classroom: the student has the opportunity to receive points for the relevant types of educational activities in lectures and laboratory classes, provided by the RSO 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 under the guidance of the teacher;*
- *rules of protection of laboratory works: only individual protection of laboratory works, and collective (as a part of crew) is allowed. In both cases, the individual responses of each student are evaluated.*
- *rules of protection of individual tasks: protection of settlement and graphic work on discipline is carried out individually and only in case the student does not agree with the accrued points on results of check of RGR (on condition of observance of the calendar plan of performance of RGR);*
- *rules for assigning incentive and penalty points: incentive and penalty points are not included in the main scale of the RSO, and their amount does not exceed 10% of the starting scale. Incentive points are awarded for participation in faculty and institute competitions, participation in faculty and institute scientific conferences. Penalty points are awarded for late performance of RGR and untimely protection of laboratory work.*
- *policy of deadlines and rearrangements: untimely execution of RGR and untimely protection of laboratory works provide accrual of penalty points. If the student did not pass or did not appear at the MCR, his result is estimated at 0 points. Interpretation of MCR results is not provided; rearrangement of protection of laboratory works occurs if results of protection are not satisfactory.*
- *Academic Integrity Policy: 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 conduct of individuals and provides a policy of academic integrity for people who work and study at the university, which they should be guided in their activities, including the study and preparation of tests in the discipline "Mathematical methods in electromechanics";*
- *when using digital means of communication with the teacher (mobile communication, e-mail, correspondence in the environment Google Classroom) it is necessary to adhere to generally accepted ethical norms, in particular to be polite and to limit communication during the teacher's working hours.*

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

A student's credit module rating consists of the points he receives for:
1) attending answers to control questions up to 13 lectures;
2) performance and protection of 8 practical works;
3) preparation of the abstract;

3) performance of 2 modular control works;

4) passing the test (optional).

Rating points system

1. ***Answers to control questions to the lecture material (rlob):***

The weight score is 2. The maximum number of points for all 13 lectures is 26 points. Points are awarded for 1 lecture according to the following criteria:

- correct and timely complete answers to all control questions - 2 points for each lecture;

- delay from 2 to 4 weeks with answers to control questions - up to 1.5 points for each lecture;

- Delay of more than 4 weeks with answers to control questions - up to 1 point for each lecture.

2. ***Execution and protection of laboratory works (rlab):***

The weight score is 5. The maximum number of points for all 8 practical works is 40 points. The maximum score for 1 laboratory work is distributed as follows: performance - 2 points; protection - 3 points ;. Scoring for 1 laboratory work is carried out according to the following criteria:

- timely and correct performance of the practical task and submission of the report in full and with observance of rules of registration according to rules - to 5 points;

- submission of a report on delays from 2 to 4 weeks - up to 4 points;

- submission of a report on delays greater than 4 weeks - up to 2 points;

- non-independent work (copying programs and reports) - 0 points.

Timely submission of the report on the performed laboratory work is considered to be its submission not later than 1 day before the next laboratory lesson.

3. ***Preparation of the abstract (rr):***

The weight score is 18. The maximum score for 1 abstract is distributed as follows: performance - 12 points; protection - 6 points ;. Scoring for 1 abstract is carried out according to the following criteria:

- timely and high-quality preparation of the abstract in compliance with the rules of design - 18 points;

- minor errors in the use of technical terminology and minor deviations from the rules of design - up to 15 points;

- many errors in the use of technical terminology and significant deviations from the rules of design - up to 10 points;

- non-independent work (copying programs and reports) - 0 points.

Timely submission of the abstract is considered to be submitted no later than 1 week before the test. 3-5 penalty points are awarded for late submission.

3. Modular control work (rm):

The weight score is 8. The maximum number of points for 1 modular test lasting 2 hours is 9. The calculation of points for 1 MCR is carried out according to the following criteria:

- "excellent", complete answer (not less than 90% of the required information) - 8-9 points;

- "good", a sufficiently complete answer (at least 75% of the required information), or a complete answer with minor inaccuracies - 6-7 points;

- "satisfactory", incomplete answer (not less than 60% of the required information) and minor errors - 4-5 points;

- "unsatisfactory", unsatisfactory answer (does not meet the requirements for 3 points) or absence during the work - 0 points.

Certification

According to the results of educational work for the first 8 weeks, the "ideal student" must score 41 points (6 lectures, 3 practical works, 1 MCR). At the first attestation (8th week) the *student receives "credited" if his current rating is not less than 50% of the maximum points, ie 20 points.*

According to the results of 16 weeks of study, the "ideal student" must score 79 points (12 lectures, 7 practical works, 2 MCR). At the second attestation (16th week) the student receives "credited" if his current rating is not less than 39 points.

General rating and test control work

The maximum amount of points from the credit module is 100 (rl + rlab + rm + rr). A necessary condition for admission to the test is a complete syllabus of lectures, completed and credited laboratory work. To receive credit from the credit module "automatic" you must have a rating of at least 60 points, as well as the conditions of admission to credit.

Students who have a rating of less than 60 points at the end of the semester, as well as those who want to improve their score in the ECTS system, perform a test. At the same time, the points scored by the student are canceled, except for the points for DKR (rr), and the grade for the test is final. Tasks of control work consist of two questions according to the subject of the working curriculum.

Each test question (r1, r2) is evaluated in 40 points according to the evaluation system:

- "excellent", complete answer (not less than 90% of the required information) - 35-40 points;

- "good", a sufficiently complete answer (at least 75% of the required information), or a complete answer with minor inaccuracies - 27-34 points;

- "satisfactory", incomplete answer (not less than 60% of the required information) and minor errors - 20-26 points;

- "unsatisfactory", unsatisfactory answer (does not meet the requirements for 3 points) - 0 points.

The sum of points for each of the two questions of the test and DCR is transferred to the credit score according to the table:

Scores	Rating
100-95	Perfectly
94-85	Very good
84-75	Fine
74-65	Satisfactorily
64-60	Enough
Less than 60	Unsatisfactorily
Admission conditions are not met	Not allowed

9. Additional information on the discipline (educational component)

List of topics that are submitted for semester control

1. *Statement of the problem of optimal control*
2. *Definition of functionality*
3. *Optimality criteria*
4. *Classification of optimal control problems*
5. *The problem of determining the unconditional extremum. Euler's equation. Terms Legendre*
6. *The problem of determining the conditional extremum. Lagrange's equation*

7. *Pontryagin's maximum principle. Feldbaum's theorem on n intervals*
8. *Types of electricity losses in electric drive systems*
9. *Optimal BP control according to the strategy "Maximum torque per Ampere"*
10. *Optimal BP management according to the strategy "Minimization of copper losses"*
11. *Optimal BP management according to the strategy "Minimization of the amount of losses in copper and steel"*
12. *Optimal management of SDPM according to the strategy "Maximum torque per Ampere"*
13. *Optimal SDPM control according to the strategy "Maximum torque per Volt"*
14. *Analysis of losses on magnetization and demagnetization of a fixed vector-controlled BP at abrupt change of a stream-forming component of a stator current*
15. *Optimal control of magnetization and demagnetization processes of vector-controlled BP (search for extremals)*
16. *Optimal control of magnetization and demagnetization processes of vector-controlled BP at the linear law of change of flux coupling of a rotor*
17. *Optimal control of magnetization and demagnetization processes of vector-controlled BP with exponential law of change of flux coupling of rotor*
18. *Energy efficient optimal control of the position electric drive*
19. *The terminal problem of optimal control of a positional electric drive*
20. *The task of maximum performance of the positional electric drive*
21. *Synthesis of the control law of the positional electric drive, optimal in terms of speed*
22. *Synthesis of a closed position transmitter for a control system for positional electric drive, optimal for speed*
23. *Features of synthesis of the control system of the positional electric drive optimum on speed, without the setting device*
24. *Statement of the problem of damping the oscillations of the load suspended on a flexible rope to the crane mechanism. Determination of the period of oscillations*
25. *Synthesis of a three-stage trolley control diagram for optimal load damping performance in the presence of restrictions on acceleration and speed*
26. *Synthesis of three-stage in the presence of restrictions on effort and speed*
27. *What is the principle of quasi-optimal control of the crane mechanism?*
28. *Determination of parameters of the quasi-optimal three-stage diagram of trolley control for damping of cargo oscillations.*

Certificates of distance or online courses on the subject can be credited subject to compliance with the requirements set out in Order № 7-177 of 01.10.2020 On approval of the provisions on recognition in the KPI. Igor Sikorsky learning outcomes acquired in non-formal / informal education

Work program of the discipline (syllabus)

made up Professor of the Department of Automation of Electromechanical Systems and Electric Drive,

Ph.D. Tolochko O.I. .____________

and associate professor of automation of electromechanical systems and electric drive,

Ph.D. Priymak BI

Approved Department of Automation of Electromechanical Systems and Electric Drive

(Minutes № ___ of _____________)

Agreed Methodical commission of the faculty (protocol № __ from _______)