Federal State Autonomous Educational Institution of Higher Education
"Russian Peoples' Friendship University named after Patrice Lumumba"

Academy of Engineering
(name of the main educational unit (POU) - developer of the EP HE)

COURSE SYLLABUS

OPTIMAL CONTROL METHODS
(name of discipline/module)

Recommended by the Didactic Council for the Education Field of:

27.03.04 CONTROL IN TECHNICAL SYSTEMS
(code and name of the area of training/specialty)

The course instruction is implemented within the professional education programme of higher education:

DATA ENGINEERING AND SPACE SYSTEMS CONTROL
(name (profile/specialization) EP HE)

2024

1. GOAL OF DISCIPLINE MASTERING

The discipline “Optimal Control Methods” is included in the bachelor’s program “Data Engineering and Space Systems Control” in the direction of 27.03.04 “Control in Technical Systems” and is studied in the 6th, 7th semesters of the 3rd and 4th courses. The discipline is implemented by the Department of Mechanics and Control Processes. The discipline consists of 3 sections and 23 topics and is aimed at studying the fundamental principles of the maximum principle of L.S. Pontryagin, dynamic programming, numerical methods of optimal control, analysis of the main methods for solving typical problems and familiarization with the scope of their application in professional activities.

The purpose of mastering the discipline is to develop fundamental knowledge and skills in applying problem solving methods necessary for professional activities, increasing the overall level of students' literacy in management methods.

2. REQUIREMENTS FOR THE RESULTS OF MASTERING THE DISCIPLINE

Mastering the discipline “Optimal control methods” is aimed at developing the following competencies (parts of competencies) in students:

Table 2.1. List of competencies formed in students when mastering the discipline (results of mastering the discipline)

Cipher	**Competence**	**Indicators of Competency Achievement** (within this discipline)
GC-12	Able to search for the necessary sources of information and data, perceive, analyze, remember and transmit information using digital means, as well as using algorithms when working with data received from various sources in order to effectively use the information received to solve problems; evaluate information, its reliability, build logical conclusions based on incoming information and data	GC-12.1 Searches for the necessary sources of information and data, perceives, analyzes, remembers and transmits information using digital means, as well as using algorithms when working with data received from various sources in order to effectively use the received information to solve problems; GC -12.2 Evaluates information, its reliability, builds logical conclusions based on incoming information and data;
GPC -11	Able to understand the operating principles of modern information technologies and use them to solve professional problems	GPC-11.1 Knows digital methods and technologies used in professional activities; GPC -11.2 Able to apply digital methods and technologies in professional activities to study and model objects of professional activities, data analysis, and presentation of information; GPC-11.3 Confident in digital methods and technologies in professional activities (in the field of management in technical systems) for: studying and modeling objects of professional activity, data analysis, presentation of information;
GPC -3	Able to use fundamental knowledge to solve basic control problems in technical systems in order to improve in professional activities	GPC-3.1 Knows the theoretical foundations and principles of mathematical modeling; GPC -3.2 Able to develop and use methods of mathematical modeling, information technologies to solve problems of applied mathematics; GPC-3.3 Possesses practical skills in solving problems of applied mathematics, methods of mathematical modeling, information technologies and the basics of their use in professional activities, professional thinking skills and an arsenal of methods and approaches necessary for the adequate use of methods of modern mathematics in theoretical and applied problems;

Cipher	Competence	Indicators of Competency Achievement (within this discipline)
GPC -8	Capable of setting up measuring and control equipment and systems and performing their routine maintenance	GPC -8.1 Knows the parameters and characteristics of measuring and control equipment and complexes; GPC -8.2 Able to carry out routine maintenance of measuring and control equipment and complexes; GPC -8.3 Provides adjustment of measuring and control equipment and complexes and their routine maintenance;
GPC -9	Able to perform experiments using given methods and process the results using modern information technologies and technical means	GPC -9.1 Knows modern information technologies and technical means; GPC -9.2 Able to use modern information technologies and technical means to process the results of experiments; GPC -9.3 Possesses modern information technologies and technical means for performing experiments and processing results;
PC-1	Capable of collecting, processing and interpreting modern scientific research data necessary to draw conclusions on relevant scientific research, including Earth remote sensing data	PC-1.1 Knows modern methods of how to collect, process and interpret modern scientific research data necessary to form conclusions on relevant scientific research; PC-1.2 Able to apply modern methods and tools for processing and interpreting scientific research data; PC-1.3 Possesses the basic skills of collecting, processing and interpreting modern scientific research data necessary to form conclusions on relevant scientific research;
PC-4	Able to formulate, analyze and solve engineering problems in the field of ballistics, propulsion mechanics and spacecraft motion control based on professional knowledge	PC-4.1 Knows the basic concepts and basic algorithms for solving problems in the field of ballistics, motion mechanics and motion control based on automated and automatic systems; PC-4.2 Able to solve engineering problems of an analytical nature in the field of ballistics, motion mechanics and motion control of spacecraft based on professional knowledge; PC-4.3 Possesses the skills of using mathematical methods for processing information obtained as a result of experimental research, basic methods of analyzing the mechanics of motion and controlling the motion of spacecraft based on standard methods and software packages;

3. PLACE OF DISCIPLINE IN THE STRUCTURE OF HE EP

Discipline "Optimal control methods" refers to the mandatory part of block 1 “Disciplines (modules)” of the educational program of higher education.

As part of the educational program of higher education, students also master other disciplines and/or practices that contribute to achieving the planned results of mastering the discipline “Optimal Control Methods”.

Table 3.1. List of components of EP HE that contribute to achieving the planned results of mastering the discipline

Cipher	Name of competency	Previous disciplines/modules, practices*	Subsequent disciplines/modules, practices*
GC-12	Able to search for the necessary sources of information and data, perceive, analyze, remember and transmit information using digital means, as well as using algorithms when working with data received from various sources in order to effectively use the	Research work / Scientific research work; Automatic Control Theory; Analysis of Geoinformation Data; *Fundamentals of information security and cyber resilience***; *Fundamentals of information security and cyber resilience***;	Technological Training; Undergraduate practice / Pre-graduate practice;

Cipher	Name of competency	Previous disciplines/modules, practices*	Subsequent disciplines/modules, practices*
	information received to solve problems; evaluate information, its reliability, build logical conclusions based on incoming information and data		
GPC-3	Able to use fundamental knowledge to solve basic control problems in technical systems in order to improve in professional activities	Research work / Scientific research work; Mathematical analysis; Space Flight Mechanics; Theoretical Mechanics; Numerical Methods; Automatic Control Theory; Algebra and Geometry; Theory of Probability and Mathematical Statistics; Differential equations; complex analysis; Analysis of Geoinformation Data;	Technological Training; Undergraduate practice / Pre-graduate practice;
GPC -8	Capable of setting up measuring and control equipment and systems and performing their routine maintenance		Undergraduate practice / Pre-graduate practice;
GPC -9	Able to perform experiments using given methods and process the results using modern information technologies and technical means	Computer Science and Programming; Analysis of Geoinformation Data; Basic Military Training. Life Safety;	Undergraduate practice / Pre-graduate practice; Technological Training;
GPC -11	Able to understand the operating principles of modern information technologies and use them to solve professional problems	Space Flight Mechanics;	Undergraduate practice / Pre-graduate practice; Technological Training;
PC-1	Capable of collecting, processing and interpreting modern scientific research data necessary to draw conclusions on relevant scientific research, including Earth remote sensing data	Research work / Scientific research work; Space Flight Mechanics; Numerical Methods; Automatic Control Theory; Computer Science and Programming; *Discrete mathematics***; *Discrete Math***; Analysis of Geoinformation Data;	Technological Training; Undergraduate practice / Pre-graduate practice;
PC-4	Able to formulate, analyze and solve engineering problems in the field of ballistics, propulsion mechanics and spacecraft motion control based on professional knowledge	Research work / Scientific research work; Space Flight Mechanics; Theoretical Mechanics;	Technological Training; Undergraduate practice / Pre-graduate practice;

* - to be filled out in accordance with the competency matrix and SUP EP VO

** - elective disciplines/practices

4. SCOPE OF DISCIPLINE AND TYPES OF STUDY WORK

The total labor intensity of the "Optimal Control Methods" discipline is "10" credit units.

Table 4.1. Types of educational work by periods of mastering the educational program of higher education for full-time study.

Type of educational work	**TOTAL,**ac.ch.		**Semester(s)**	
			6	**7**
Contact work, ac.ch.	*162*		*72*	*90*
Lectures (LC)	72		36	36
Laboratory work (LR)	72		36	36
Practical/seminar sessions (SZ)	18		0	18
Independent work of students, ac.ch.	*144*		*81*	*63*
Control (exam/test with assessment), academic degree.	*54*		*27*	*27*
Total labor intensity of the discipline	**ac.ch.**	***360***	*180*	*180*
	credit units	***10***	*5*	*5*

5. CONTENT OF DISCIPLINE

Table 5.1. Contents of the discipline (module) by type of academic work

Section number	Name of the discipline section	Contents of the section (topic)		Type of educational work*
Section 1	Optimal control theory. Maximum principle L.S. Pontryagin.	1.1	Statement of optimal control problems. Basic concepts. Examples of optimal control problems.	
		1.2	Problems with a free right end of the trajectory. Formula for increasing functionality.	
		1.3	Maximum principle L.S. Pontryagin for problems with a free right endpoint. Formulation and proof.	
		1.4	Linear problems with a free right end. The maximum principle as a necessary and sufficient condition.	
		1.5	Formulation of the maximum principle for various classes of optimal control problems: a) two-point problems; b) optimal performance problem; c) problems with boundary conditions, transversality conditions; d) autonomous and non-autonomous systems; e) tasks with fixed and non-fixed process completion time; e) tasks with integral and terminal functionality; g) problems with parameters.	
		1.6	Examples of optimal control problems. Performance problem.	
		1.7	The concept of synthesis of optimal control.	
		1.8	Relationship between the maximum principle and classical calculus of variations. Derivation of the Euler equation and the Legendre-Clebsch conditions from the maximum principle. Jacobi condition.	
Section 2	Dynamic programming	2.1	Managed multi-step processes. The principle of optimality.	
		2.2	Dynamic programming method for multi-step control processes.	
		2.3	Dynamic programming method for optimal control problems.	
		2.4	Bellman differential equation. Statement of problems for the Bellman equation. Examples.	
		2.5	Relationship between the dynamic programming method and the maximum principle. Derivation of transversality conditions using the dynamic programming method.	
		2.6	Linear control systems with quadratic functionality. Construction of a synthesis of optimal control.	
Section 3	Numerical methods for optimal control	3.1	Numerical methods based on reducing optimal control problems to boundary value problems using the maximum principle.	
		3.2	Using methods for solving systems of algebraic equations to solve boundary value problems. Newton's method and its modifications.	
		3.3	Numerical methods for minimizing functions of several variables. The concept of linear and nonlinear programming. Gradient method. Method of penalty functions.	
		3.4	Numerical methods based on varying control functions. Gradient method in control space. Accounting for restrictions on executive functions.	

Section number	Name of the discipline section	Contents of the section (topic)		Type of educational work*
			Accounting for boundary conditions and phase restrictions using the penalty function method. Accounting for boundary conditions using the gradient design method.	
		3.5	Method of successive approximations in the space of control functions. Ways to improve convergence and modify the method. Examples.	
		3.6	Small parameter method for weakly controllable systems.	
		3.7	Numerical methods based on varying phase coordinates in space. Dynamic programming method. Full and partial search. "Wandering tube" method.	
		3.8	The concept of an elementary operation and methods of its construction. Construction of an elementary operation for flight dynamics problems.	
		3.9	Method of local variations. Application of the method of local variations to various variational problems. Variational problems with non-additive functionals. Variational problems in partial derivatives.	

* - to be filled out only for full-time education: LC – lectures; LR – laboratory work; SZ – practical/seminar classes.

6. MATERIAL AND TECHNICAL SUPPORT OF DISCIPLINE

Table 6.1. Material and technical support of the discipline

Audience type	Auditorium equipment	Specialized educational/laboratory equipment, software and materials for mastering the discipline (if necessary)
Lecture	An auditorium for conducting lecture-type classes, equipped with a set of specialized furniture; board (screen) and technical means of multimedia presentations.	
Laboratory	An auditorium for conducting laboratory work, individual consultations, ongoing monitoring and intermediate certification, equipped with a set of specialized furniture and equipment.	
Seminar	An auditorium for conducting seminar-type classes, group and individual consultations, ongoing monitoring and intermediate certification, equipped with a set of specialized furniture and technical means for multimedia presentations.	
For independent work	An auditorium for independent work by students (can be used for seminars and consultations), equipped with a set of	

Audience type	Auditorium equipment	Specialized educational/laboratory equipment, software and materials for mastering the discipline (if necessary)
	specialized furniture and computers with access to EIOS.	

* - the audience for independent work of students is MANDATORY!

7. EDUCATIONAL, METHODOLOGICAL AND INFORMATIONAL SUPPORT OF DISCIPLINE

Main literature:

1. Pontryagin L.S., Boltyansky V.G., Gamkrelidze R.V., Mishchenko E.F. Mathematical theory of optimal processes.M.: Nauka, 1969.

2. Ivanov V.A., Faldin P.V. Theory of optimal automatic control systems.M.: Nauka, 1981. 336 p.

3. Roitenberg Ya.N. Automatic control, M.: Nauka, 1971.396 pp.

4. Afanasyev V.N., Kolmanovsky V.B., Nosov V.R. Mathematical theory of design of control systems.M.: Higher School, 2003.

Additional literature:

1. Gelfand I.M., Fomin S.V. Calculus of variations.M.: Fizmatlit, 1961.

2. Boltyansky V.G. Mathematical methods of optimal control.M.: Nauka, 1969.

3. Bellman R., Dreyfus S. Applied problems of dynamic programming.M.: Nauka, 1965.

4. Moiseev N.N. Elements of the theory of optimal systems.M.: Nauka, 1975.

5. Chernousko F.L., Banichuk N.V. Variational problems of mechanics and control.Numerical methods. M.: Nauka, 1973.

6. Chernousko F.L., Akulenko L.D., Sokolov B.N. Oscillation control.M.: Nauka, 1980.

7. Chernousko F.L. Estimation of the phase state of dynamic systems.M.: Fizmatlit, 1988.

8. Chernousko F.L., Ananyevsky I.M., Reshmin S.A. Methods for controlling nonlinear mechanical systems.M.: Fizmatlit, 2006.

9. Chernousko FL, Ananievski IM, Reshmin SA Control of Nonlinear Dynamical Systems. Methods and Applications. Berlin, Heidelberg: Springer, 2008, 396 p.

10. Lee E.B., Markus L. Fundamentals of optimal control theory / Transl. from EnglishM.: Nauka, 1972. 576 p.

11. Pontryagin L.S. Maximum principle. M.: Foundation for Mathematical Education and Enlightenment, 1998.

Resources of the information and telecommunications network "Internet":

1. EBS of RUDN University and third-party EBS, to which university students have access based on concluded agreements

- Electronic library system of RUDN University - EBS RUDN Universityhttp://lib.rudn.ru/MegaPro/Web
- EBS "University Library Online"http://www.biblioclub.ru
- EBS Lawhttp://www.biblio-online.ru
- EBS "Student Consultant"www.studentlibrary.ru
- EBS "Trinity Bridge"

2. Databases and search engines

- electronic fund of legal and regulatory technical documentationhttp://docs.cntd.ru/
- Yandex search enginehttps://www.yandex.ru/
- search systemGoogle https://www.google.ru/
- abstract databaseSCOPUS http://www.elsevierscience.ru/products/scopus/

Educational and methodological materials for students' independent work when mastering a discipline/module:*

1. A course of lectures on the discipline "Optimal control methods".

* - all educational and methodological materials for students' independent work are posted in accordance with the current procedure on the discipline page in TUIS!

8. ASSESSMENT MATERIALS AND POINT-RATING SYSTEM FOR ASSESSING THE LEVEL OF COMPETENCIES FOR A DISCIPLINE

Evaluation materials and point-rating system* for assessing the level of development of competencies (parts of competencies) based on the results of mastering the discipline"Optimal control methods" are presented in the Appendix to this Work Program of the discipline.

* - OM and BRS are formed on the basis of the requirements of the relevant local regulatory act of RUDN University.

DEVELOPER:

Professor		Reshmin Sergey Alexandrovich
Position	*Signature*	*Last name I.O.*

HEAD OF DEPARTMENT:

Head of the department		Razumny Yuri Nikolaevich
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