Syllabus
Course Program
Course Program

Nonlinear Processes and Models

Specialty
113 – Applied Mathematics

Institute
Institute of Computer Modeling, Applied Physics and Mathematics

Educational program
Computer and Mathematical Modeling

Department
Mathematical Modelling and Intelligent Computing in Engineering (161)

Level of education
Master's level (1 year 4 months)

Course type
Special (professional), Mandatory

Semester
1

Language of instruction
English

Lecturers and course developers

Oleksiy Larin (responsible lecturer)

Oleksiy.Larin@khpi.edu.ua

Doctor of Technical Sciences, Professor, work experience - 15 years
Specialist in the field of computational mechanics, probabilistic modeling and reliability prediction. The main focus of scientific works is devoted to the development of models, methods, approaches and algorithms of computer modeling and statistical analysis of engineering systems, in particular with random parameters. Author of more than 150 scientific and methodical works

More information about the teacher on the website of the department

Volodymyr Gryschenko (assistant)

Volodimir.Grischenko@khpi.edu.ua

Ph.D in Technical Science,, Associate Professor of the Department of Mathematical Modeling and Intelligent Computing in Engineering
Author of more than 90 scientific and methodological publications.
Leading lecturer in the following disciplines: "Theory of Dynamic Processes-I", "Theory of Dynamic Processes-II", "Finite Element Method", "Mathematical Methods of Analysis of Machine Dynamics", "Nonlinear Processes and Models", "Modelling of Dynamic Processes".

More information about the teacher on the website of the department

General information

Summary

The discipline is aimed at mastering the basic concepts, fundamental principles and approaches of the theory of nonlinear processes. The course focuses on developing an in-depth understanding of the peculiarities of the dynamic behaviour of nonlinear systems, as well as the accompanying specific phenomena. Particular attention is paid to approximate analytical and computational methods for studying nonlinear dynamics, in particular asymptotic methods. The practical part of the course involves an independent study of a nonlinear mechanical dynamical system in a conservative formulation. The final control is an exam.

Course objectives and goals

The aim of the course is to provide students with knowledge of the basic phenomena and features of the behaviour of nonlinear dynamic systems and methods of their study; Students are provided with knowledge and practical skills in the use of analytical and computational and asymptotic methods of analysing problems of nonlinear dynamics in applied problems of mechanics.

Format of classes

Lectures, practical classes, consultations, mandatory individual practical assignment. Final control in the form of an exam.

Competencies

GC7. Ability to think abstractly, analyse and synthesise.
PC2. Ability to conduct scientific research aimed to develop new and adapt existing mathematical and computer models to study various processes, phenomena and systems, conduct appropriate experiments and analyse the results
PC3. Ability to develop methods and algorithms for the construction, research and software implementation of mathematical models in engineering, physics, biology, medicine and other fields and to analyse them.
PC9. The ability to mathematically formalise the formulation of scientific and practical problems, to choose a mathematical analytical or numerical method of its solution, which ensures the required accuracy and reliability of the result.
PC10. Ability to develop mathematical methods and algorithms for computer modelling of nonlinear physical phenomena and processes in innovative technological systems.
PC11. Ability to mathematically describe various dynamic processes that can occur in systems of design objects.

Learning outcomes

LO4. Build mathematical models of complex systems and choose methods of their research, implement the built models in software and check their adequacy using computer technologies.
LO9. Be able to analyse and design systems with large amounts of data, apply and adapt methods of knowledge acquisition, methods of evaluation and interpretation of the found patterns.
LO16. Be able to develop mathematical methods and algorithms for computer modelling of nonlinear physical phenomena and processes in innovative technological systems.
LO17. Possess knowledge of the mathematical description of various dynamic processes that can occur in systems of design objects.
LO18. To understand the essence of scientific and technical problems in professional activities, to apply appropriate mathematical models for the study of mechanical objects and processes.

Student workload

The total scope of the discipline is 120 hours (4 ECTS credits): lectures – 32 hours, practical classes – 16 hours, self-study – 72 hours. Control practical assignment. Final control in the form of an exam.

Course prerequisites

Basic concepts of mathematical analysis, theory of differential equations, theoretical mechanics, theoretical foundations of modelling physical processes, theory of dynamic processes.
Additionally, experience in using mathematical software for numerical modelling and solving differential equations is recommended. Knowledge of programming languages, such as MATLAB/Octave, Python or others, will be useful for completing practical tasks and IPA within the course.

Features of the course, teaching and learning methods, and technologies

Teaching and learning methods include traditional lectures for theoretical foundations and practice. In fact, this discipline is essentially theoretical, providing in-depth scientific competences. The practical part is structured in two approaches: classical practical classes where examples of theoretical concepts are considered (this is actually very close to interactive lectures in essence) and the analysis of tasks assigned to the IPA. To consolidate practical skills, it is proposed to perform individual practical assignments (IPA). In this case, the relevant practical classes are structured as follows: in the form of seminar-type classes where, within the framework of consultations, examples of students' solutions to the task set in the IPA for the virtual version are considered. At the same time, the implementation of the IPA is carried out in the system of symbolic mathematics or using the Python language in the PyCharm environment (at the choice of most students in the group). The following practices take place in the form of consultations on the problems encountered by the student in the implementation of the IPA (including assistance with the software part) and the defence of the results of this task. It is important to answer theoretical questions about the topic of the IPA, as well as to interpret the results and conclusions obtained.

Program of the course

Topics of the lectures

Topic 1. Basic concepts and definitions of the theory of nonlinear dynamical systems.
Issues and definitions. The correlation between linear and nonlinear. Nonlinear and linear characteristics of systems - physical examples.
Topic 2. Classification of nonlinear systems. Fundamental phenomena.
Non-isochrony, Anharmonicity, Bifurcations, Multistability, Self-oscillations, Dynamic chaos.
Topic 3. Autonomous systems.
Phase plane. General view of the system on the phase plane. Specific points, their classification. Phase portraits.
Topic 4. Conservative autonomous systems.
System potential. Transformations of the potential energy when parameters change. The relation between the potential function and the phase portrait.
Topic 5. The first integral of motion of conservative autonomous nonlinear systems.
Determination of the vibration period. Backbone curve. Hard and soft characteristics.
Topic 6. Complex dynamic behaviour of nonlinear systems.
Features of studying the dynamic behaviour of non-autonomous dynamical systems. The phase cylinder. The concept of stroboscopic Poincaré mapping.
Topic 7. Asymptotic methods of the theory of nonlinear vibrations.
Classification and scope of applications. The method of direct in a small parameter expansion.
Topic 8. Investigation of nonlinear vibrations of a conservative autonomous dynamical system with cubic nonlinearity (Duffing oscillator).
Occurrence of secular terms in the asymptotic curves of the fundamental and subharmonics.
Topic 9. Features of dissipative systems.
Main types and their characteristics. Models of dissipation.
Topic 10. Methods of averaging.
Van der Pol method. Application to the case of a Duffing oscillator with low dissipation.
Topic 11. Study of the dynamics of the system with the "dry friction".
Application of the Van der Pol method. Analysis of isochrony.
Topic 11. Study of self-vibrations of a nonlinear system.
Application of the Van der Pol method.
Topic 12. Method of motion separation.

Study of systems with strong dissipation.
Topic 13. The method of multiscales
Solution of a non-conservative autonomous dynamical system with cubic nonlinearity in the case of small dissipation.
Topic 14. Nonlinear vibrations of a non-conservative nonautonomous dynamical system.
Study of the fundamental nonlinear resonance (using the Van der Pol method).
Topic 15. Nonlinear vibrations of a non-conservative nonautonomous dynamical system.
Study of nonlinear resonance (using the method of multiscales). Analysis of sub- and ultra-resonances.
Topic 16. Methods for studying significantly nonlinear systems.
Direct linearisation methods
Topic 17. Methods for studying significantly nonlinear systems (continued)
Harmonic balance method
Topic 18. Methods for studying significantly nonlinear systems (continued)
Galerkin method
Topic 19. Nonlinear vibrations of systems with a finite number of degrees of freedom.
Nonlinear normal modes.

Topics of the workshops

There are no classes.

Topics of laboratory classes

Practical class 1.
Investigation of specific points of various nonlinear systems. Creation of phase portraits.
Practical class 2.
Investigation of conservative nonlinear systems with piecewise linear characteristics. Construction of backbone curves.
Practical class 3.
Example of IPA №1. Solving the problem of estimating a nonlinear conservative system for constructing a phase portrait and determining topological variants of motion.
Practical class 4.
Consultation and/or defense of results IPA №1.
Practical class 5.
Consultation and/or defense of results IPA №2.
Practical class 6.
Consultation and/or defense of results IPA №3.

Self-study

Processing of lecture material.
Performing of individual practical assignments:
Individual practical assignment (IPA) №1: Solving the problem of evaluating a nonlinear conservative system regarding the construction of a phase portrait, determining topological variants of motion.
Individual practical assignment (IPA) №2: Solving the problem of constructing a backbone curve for a nonlinear conservative system.
Individual practical assignment (IPA) №3: Application of asymptotic methods to solve the problem of free vibrations of a nonlinear system in a non-conservative formulation. Bringing the nonlinear model to a form that involves the use of asymptotic methods (selection of a small parameter) and comparing conservative and non-conservative solutions with numerical simulations.

Course materials and recommended reading

1. Vasylenko M.V., Alekseichuk O.M. Theory of oscillations and stability of motion. K.: Higher school, 2004.
(Василенко М.В.,Алексейчук О.М. Теорія коливань і стійкість руху. К.:Вища школа,2004)
2. S.S.Rao. Mechanical Vibrations. (5-th ed.),Pearson Education,2010.

3. Gryshchenko V M. Oscillations of systems with a finite number of degrees of freedom: Method of instruction for students of specialties 113-Applied mathematics, 122 -Computer science / Comp. V.M. Gryshchenko - Kh.: NTU "KhPI", 2023. 31 c.
(Грищенко В М. Коливання систем зі скінченним числом ступенів свободи: Метод вказівки для студентів спеціальностей 113-Прикладна математика, 122 -Комп'ютерні науки / Уклад. В.М. Грищенко - Х.: НТУ «ХПІ», 2023. 31 с.)
4. W.Thomson,M.D.Dahleh. Theory of Vibration with Applications.Pearson, 2013. 544p.
5. When studying the discipline, physical laboratory installations can be used.

Assessment and grading

Criteria for assessment of student performance, and the final score structure

Theoretical part: **36 points**
in the form of an oral exam (2 questions in the exam paper for 12 points and additional oral questions for 12 points)

Practical part of the course: **64 points**
3 individual practical assignments (IPA): IPA1 – 20 points; IPA2 - 24 points; IPA3 - 20 points. The answers to the questions on the topic of the IPA, the correctness of the interpretation of the results, and the quality of the report are assessed (up to 5 points).
Completion and defence of the IPA is an admission to the exam.

Grading scale

Total points	National	ECTS
90–100	Excellent	A
82–89	Good	B
75–81	Good	C
64–74	Satisfactory	D
60–63	Satisfactory	E
35–59	Unsatisfactory (requires additional learning)	FX
1–34	Unsatisfactory (requires repetition of the course)	F

Norms of academic integrity and course policy

The student must adhere to the Code of Ethics of Academic Relations and Integrity of NTU "KhPI": to demonstrate discipline, good manners, kindness, honesty, and responsibility. Conflict situations should be openly discussed in academic groups with a lecturer, and if it is impossible to resolve the conflict, they should be brought to the attention of the Institute's management.
Regulatory and legal documents related to the implementation of the principles of academic integrity at NTU "KhPI" are available on the website: http://blogs.kpi.kharkov.ua/v2/nv/akademichna-dobrochesnist/.

Approval

Approved by	Date	
	Date August 30, 2023	Head of the department Oleksii VODKA
	Date August 30, 2023	Guarantor of the educational and professional program (1 year 4 months) Oleksiy LARIN