Syllabus
Course Program

Mathematical Methods of Analysis of Machine Dynamics

Specialty
113 – Applied Mathematics

Institute
Institute of Computer Modeling, Applied Physics and Mathematics

Educational program
Computer and Mathematical Modelling

Department
Mathematical Modeling and Intelligent Computing in Engineering (161)

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

Course type
Special (professional), Elective

Semester
1

Language of instruction
English

Lecturers and course developers

Anton Vasiliev

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Ph.D., senior researcher, assistant professor
Experience – 20+ years. Author of 100+ scientific papers. Lecturer of the disciplines: «Computer Aided Design and Engineering», «Computer modeling of dynamics and vibration protection of rotary machines», «Modeling of nonlinear processes in CAE»
More about the lecturer on the department's website

General information

Summary

The discipline is aimed at: - mastering the basics of structural analysis of mechanisms;
- the ability to formulate problems for studying the dynamic behavior of machines under external loads;
- mastering the basic engineering methods of building their design, reduced models, theoretical - substantiation of applied approaches in machine dynamics;
- acquaintance with the basics of structural analysis in the computer mechanics system with examples in Ansys Workbench;
- skills acquisition in dynamic processes computer modeling for machine parts (sketching, geometric modeling, FE meshes generation, solving numerical problem, etc.).
The course is completed in the 1st semester and includes: 32 hours of lectures, 16 hours of laboratory (practical) classes, 72 hours of self-study work, control calculation tasks, colloquiums, essay. The final control is a test.

Course objectives and goals

Aims to underscore the significance understanding the scientific foundations for analyzing the structural dynamics of mechanisms, including the formulation of research tasks to study machine behavior under different loads. Mastering essential engineering techniques for developing analytical and simplified models, along with theoretical justification of applied approaches in machine dynamics. Developing proficiency in computer modeling of dynamic processes within machine components. Additionally, students will become acquainted with structural analysis fundamentals using computer mechanics systems like Ansys Workbench. The Course is structured into four parts to guide and inform on these aspects.

Format of classes

Lectures, laboratory classes, consultations, self-study. Final control in the form of a credit.

Competencies

PC1. Ability to solve tasks and problems that can be formalised, require updating and integrating knowledge, in particular in conditions of incomplete information.
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.
PC4. Ability to develop and research mathematical and computer models, conduct computational experiments and solve formalised problems using specialised software.
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.
LO14. To have the knowledge 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.
LO17. Possess knowledge of the mathematical description of various dynamic processes that can occur in systems of design objects.

Student workload

The total volume of the course is 120 hours (4 ECTS credits): lectures - 32 hours, laboratory classes -16 hours, self-study - 72 hours.

Course prerequisites

Basic concepts of mathematical analysis and theory of differential equations (trigonometry, matrix, differential and integral equation, numerical methods, FEM), Mechanics (kinematics, dynamics, structural analysis, theory of vibrations), theoretical foundations of modeling physical processes, theory of dynamic processes, mechanical design, CAD. Skills in CAD.

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

Theoretical material is consolidated in laboratory classes. Ansys Workbench computer modeling tools are used.
To master the basics of computer modeling of dynamics and vibration protection of machines, the necessary conditions are the complete and correct execution of Control Tasks, Workshops and Essay. Based on they results an survey about theoretical foundations on the topic students obtain a grade scores. It is necessary to work with educational literature and literature on electronic media on the Internet.

Program of the course

Topics of the lectures

Topic 1. Introduction to course.
1.1. Subject of machine dynamics and the discipline tasks.
1.2. The main research directions and applied aspects of the dynamic processes use in machines design.

1.3. Classification of dynamics problems and processes in machine units.
1.4. List of CAE software for simulating Dynamic processes in mechanisms and machines.
Topic 2. The concept of the "Machine", machine types classification. Rotary and piston machines. Types of models for simulations (rigid-body motion, kinetostatic models and models with elastic (flexible) units).
2.1. General principles of building computational machines models with a finite number of degrees of freedom. Machine models units: inertial, elastic, dissipative and power elements.
2.2. The general principle of constructing reduced (equivalent) machines models according to the criterion of energy equivalence. Reduction of masses, moments of inertia, stiffness's and forces in machines; with gears, belts and other transmissions. Reduced models examples.
2.3 Math methods for modeling behavior of 1 DoF - Multi-DoF systems.
2.4 Numerical simulation of 1 DoF - Multi-DoF systems with Computer Software.
2.5. Classification of internal and external forces in machines. Typical technological loads. Drive motors.
2.6. Static mechanical characteristics of engines. Experimental internal combustion engine power characteristics (mechanical characteristics and indicator diagram). Mechanical characteristics of a 3-phase induction motor with a squirrel-cage rotor. Electric drive calculation basics.
2.7 Mechanism modeling in CAE.
Topic 3. The machines operation theory.
3.1. Energy characteristics of elastic mechanical systems (mechanical systems with flexible, non-rigid units). Forces kinetic and potential energy and work. System motion equations of material points in general coordinates. Lagrange's equation of the second kind. General machine discrete model motion equation in matrix form (Lagrange-d'Alembert equation).
3.2. Features and work principles of machines with internal combustion engines (ICE). Equations of an in-line multi-cylinder ICE motion.
3.3. Machine with rigid links motion equations (with one degree of freedom). Machine reduced characteristics specifications. Rotary and piston machines. First integral of a machine (with rigid units and one degree of freedom) motion equation.
3.4. Introduction to mathematical calculations using the systems of symbolic mathematics and computer mechanics Ansys Workbench.
3.5. Research methods. Transient dynamic process in machines (with rigid units) for the case of different engines types. Numerical modeling of the machine unit's dynamics under different operating conditions using the CAE Software.
3.6. Energy analysis of machine motion at different ratios of engine power and technological load. Theory of machine operation.
3.7. The main directions of research in machine dynamics. The concept of steady-state machine motion (with rigid units and limited power engine). The concept of dangerous vibrations in machines. The general problem of vibration protection of machines and mechanisms. Elimination of resonant and critical modes in machines.
Topic 4. Computer modeling of dynamic processes in machines with CAE

Topics of the workshops

Non Applicable

Topics of the laboratory classes

Topic 1. Repeating the basic principles of the linear vibrations theory. An example of solving the free oscillations problem in a system with a finite degrees of freedom number. Resonance in mechanical systems.
2. Structural analysis of mechanisms and machines. Parts, links, units, joints. Kinematic pairs, kinematic chains. Malyshev's and Chebyshev's structural formulas. Examples of mechanisms structural diagrams. Simple mechanisms examples.
2.1. Modeling of dynamic processes in mechanisms by means of computer technology. Fundamentals of structures and system's analysis for computer mechanics (on the example of Ansys Workbench). Geometric modeling in Ansys Workbench (Ansys Discovery module).
2.2. Modeling of dynamic processes in mechanisms by means of computer technology. Fundamentals of design analysis in the system of symbolic mathematics.
Topic 3. General principles of creating discrete computational models (with a finite degrees of freedom number) for general machines. Mass, elastic, dissipative and power elements in machine models.

3.1 Creating of road and transport machines reduced models (with a finite degrees of freedom number). Examples of reduced models construction for the: crane lifting mechanism, equivalent models in piston machines etc...
3.2. Mechanism modeling in CAE - Ansys Workbench (creating solid geometry; generating a FE mesh; numerical solving of problems).
Topic 4. System of material points motion equations in generalized coordinates.
4.1. Energy characteristics of elastic mechanical systems. Forces work and energy (kinetic and potential). Lagrange's equation of the second kind. Behavior of a system with the 1st degree of freedom under the action of an instantaneous load (″lift with pickup″ mode of operation).
4.2. Mechanism modeling in CAE - Ansys Workbench (Graphical tools for post-proc: Displacements, Velocities, Accelerations. Strains. Stresses, von Mises stress).
Topic 5. Forced oscillations in a technological machines models (with one degree of freedom) under the periodic load action. Use numerical algorithms for integration process of the machine motion equation (with rigid units and one degree of freedom).
5.1 Dynamics of the lifting mechanism of an overhead crane with a limited power engine.
Topic 6. Mechanism modeling in CAE - Ansys Workbench. Computer modeling of the mechanism units connection with kinematic pairs of class V (rotary gear), class IV (cylindrical gear), class III (spherical joint).
Topic 7. Calculation of the transient and steady dynamics modes a machine (with rigid links under the influence of a given load) operation (theory of machine operation).

Self-study

Information on self-study and individual assignments (reports, course projects, etc.), if it is necessary according to the plan. Also, methods of control and assessment of self-study.
1. Study lecture material and prepare for laboratory classes.
2. To consolidate the course material, it is mandatory to complete the test workshops:
- TW1 "Structural analysis of the industrial robot manipulator as example of spatial mechanism".
- TW2 " Computer modeling of the mechanism units connection with kinematic pairs of class V (rotary gear), class IV (cylindrical gear)",
- TW3 "Construction of a machine motion reduced dynamic model (with rigid and elastic (flexible, non-rigid) units) based on the principle of energy equivalence.
3. Preparation for the Colloquium. Based on the results of the TW, a Colloquium is held with a survey of theoretical foundations on the topic.
4. For an in-depth acquaintance with the problems of machine dynamics, students can consider the following topics:
- Classification of machines by their design and structural classification of mechanisms.
- Dangerous vibrations in machines. Ways to counteraction to them.
- CAD/CAE systems in design tasks.
- Math tools in the study of applied machine dynamics.
- Research areas and applied aspects of the dynamic processes in machines use.
- Types of drive motors.

Course materials and recommended reading

Compulsory materials
1. V. S. Loveikin, Y. O. Romasevich, Machine dynamics: a textbook. 227c.
2. Theory of mechanisms and machines. A course of lectures for students of the specialty "Dynamics and strength of machines".K.: NTUU "KPI", 2010. 243c.
3. Grishchenko V M, Svirhun O A, Kalinin E I, Savchenko V
4. Alok Sinha. Vibration of mechanical systems. The Pensylvania State University. 2010. 330p. ISBN-13 978-0-511-77527-7
5. Allen S. Hall. Machine Design. Allen S. Hall., Alfred R. Holowenko, Herman G. Laughlin. McGraw-Hill Inc. 1961. 351 p. ISBN 07-025595-4
6. Ullman, David G. - The mechanical design process / David G. Ullman. - 4th ed. McGraw-Hill Inc. 1944. 448 p. ISBN 978-0-07-297574-1
7. Mechanical vibrations. Theory and applications. S. Graham Kelly. 2011.. ISBN-13: 978-1-4390-6214-2
8. http://courses.ansys.com

Additional materials
1. Calculations in the design of machines. Construction of models of transmission and internal combustion engine parts: methodical instructions for conducting practical classes for students of the second (master's) level of higher education. Sectoral engineering / KhNTUA: Compiled by V M Hryshchenko, O A Svirhun, E I Kalinin, V B Savchenko, Kharkiv, 2019. 28c.
2. Tomas B. Theory of Machines, Pearson Education, 1986.
3. B.V.R.Gupta. Theory of Machines: Kinematics and Dynamics. I.K.International Publishing House Pvt.Ltd, 2010.
4. S.S.Rao. Mechanical Vibrations. (5th ed.), Pearson Education, 2010.
5. S.P.Timoshenko, D.H.Jung, W.Weaver, Jr. Vibration Problems in Engineering. (4th ed.), Wiley, New York, 1974.
6. Current methodological materials.

Assessment and grading

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

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Total mark (100 points) consists of three parts:
1. Test on theory (50 points)
2. Practice (lab) passing (40 points)
3. Essay 10 points

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
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