

MECHANICS OF CONTINUUMS

Educational component work program (Syllabus)

Educational component details

Level of higher education	<i>Second (Master's)</i>
Branch of knowledge	<i>G - Engineering, manufacturing and construction</i>
Specialty	<i>G9 «Applied Mechanics»</i>
Educational program	<i>Educational and Professional Program Engineering of packaging products, processes and equipment</i>
Status of the educational component	<i>selective</i>
Form of study	<i>full-time / day</i>
Year of preparation, semester	<i>1 course, spring semester</i>
The scope of the educational component	<i>5(150)</i>
Semester control/control measures	<i>Exam</i>
Class schedule	
Language of instruction	<i>Ukrainian</i>
Information about the course leader/teachers	Lecturer: https://cpsm.kpi.ua/karvatskij-anton-yanovich.html Practical: https://cpsm.kpi.ua/karvatskij-anton-yanovich.html Laboratory: –
Course placement	<i>Link to a remote resource Google classroom, https://cpsm.kpi.ua/navchannya/sylabusy/sylabusy-2025-roku.html</i>

Educational component program

1. Description of the educational component, its purpose, subject matter and learning outcomes

The educational component "Mechanics of Continuum" is the most important link that logically combines the disparate knowledge acquired by students during the study of individual educational components into a single system of knowledge that ensures high quality of scientific and applied design and development, and has a theoretical and practical focus in the training of specialists specializing in the field of applied mechanics.

The purpose of the educational component "Mechanics of Continuum"

The purpose of the educational component is to strengthen the process of forming a complex of knowledge by students regarding the theoretical foundations of conducting research on the stressed-deformed state of solid, liquid and gaseous bodies during their interaction with each other and physical fields of various physical nature - gravitational, thermal, electromagnetic, radiation, etc.

Subject of the educational component "Mechanics of Continuum" – *methods for studying the stress-strain state of solid, liquid, and gaseous bodies during their interaction with each other and with physical fields of various physical nature - gravitational, thermal, electromagnetic, radiation, etc.*

In accordance with the purpose, the training of masters in this specialty requires strengthening the formation of the following competencies:

Integral competence:

- The ability to solve complex tasks and problems in applied mechanics or in the learning process, which involves conducting research and/or implementing innovations and is characterized by uncertainty of conditions and requirements.

General competencies:

- Ability to identify, pose and solve engineering, technical and scientific and applied problems (ZK 01);
- Ability to use information and communication technologies (ZK 02);
- Ability to generate new ideas (creativity) (ZK 03);
- Ability to learn and master modern knowledge (ZK 06);
- Ability to abstract thinking, analysis and synthesis (ZK 08).

Professional competencies:

- Ability to describe, classify and model a wide range of technical objects and processes, based on deep knowledge and understanding of the theories and practices of mechanical engineering, as well as knowledge of related sciences (FC 02);
- Ability to engineer packaging equipment to ensure its performance under operational loads and environmental influences (FC 05);
- Ability to search and analyze scientific and technical information on the engineering of technological equipment (FC 06).

According to the requirements of the educational component program "Mechanics of Continuum Media", after mastering it, students must demonstrate the following enhanced program **learning outcomes**:

- Apply specialized conceptual knowledge of the latest methods and techniques for designing, analyzing and researching structures, machines and/or processes in the field of mechanical engineering and related fields of knowledge (PRN 01);
- Use modern methods for optimizing the parameters of technical systems using systems analysis, mathematical and computer modeling, in particular under conditions of incomplete and contradictory information (PRN 04).

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

Prerequisites: The educational component "Mechanics of Continuum Media" is based on the study of the following credit modules: "Higher Mathematics", "Physics", "Chemistry", "Engineering and Computer Graphics", "Theoretical Mechanics", "Informatics", "Materials Science", "Technology of Structural Materials", "Mechanics of Materials and Structures", "Theory of Mechanisms and Machines", "Theoretical Fundamentals of Heat Engineering", "Machine Parts and Fundamentals of Design", "Fluid and Gas Mechanics", "Engineering Calculations on a PC", "Technologies and Equipment for the Production of Packaging Materials", "Packaging Technologies and Equipment", "Automated Engineering Systems", "Processes, Apparatus and Machines of the Industry", "Packaging Equipment".

Postrequisites: The educational component "Mechanics of Continuum Media" provides the following educational components: "Packaging Equipment", "CAD of Technological Equipment", "Course Project in Packaging Equipment Engineering" and "Scientific Work on the Topic of a Master's Thesis", completion of master's theses.

3. Content of the educational component

Section 1. Mechanics of continuum media in engineering calculations

Topic 1. The subject mechanics of continuum media (MC). Properties of continuum media.

Topic 2. Basic concepts, definitions and hypotheses of continuum media.

Topic 3. Introduction to tensor analysis.

Topic 4. Theory of stresses in a continuum media.

Topic 5. Types of stressed states of a continuum media.

Topic 6. Theory of deformations of a continuum media.

Topic 7. Physical equations of a homogeneous medium.

Topic 8. Laws of conservation of a continuum media.

Topic 9. Solving equations of continuum media in Cartesian and curvilinear coordinates.

4. Educational materials and resources

Basic literature

1. Mechanics of continua. [Electronic resource]: lecture notes: teaching aids for master's degree applicants in educational programs "Packaging and packaging equipment engineering" spec. 131 "Applied mechanics" and "Engineering and computer-integrated technologies for designing innovative industry equipment" spec. 133 "Industrial mechanical engineering" / A. Ya. Karvatsky, A. O. Chemerys; Igor Sikorsky Kyiv Polytechnic Institute. – 2nd ed. revised and supplemented – Electronic text data (1 file: 3.56 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2024. 214 p. URL: <https://ela.kpi.ua/handle/123456789/72094>
2. Karvatsky A. Ya. Finite element method in problems of mechanics of continuum media. Laboratory practical course on the subject [Electronic resource]: a teaching aid for students of specialties 131 "Applied mechanics", 133 "Industrial mechanical engineering", specializations "Engineering, computer modeling and design of packaging equipment", "Engineering, computer modeling and design of equipment for the production of polymer and building materials and products". Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2018. 391 p. <http://ela.kpi.ua/handle/123456789/23916>
3. Karvatsky A. Ya. Mechanics of continuum media. Theoretical foundations of "Engineering, computer modeling and design of equipment for the production of polymer and building materials and products". Kyiv: specialties 131 "Applied Mechanics", 133 "Industrial Mechanical Engineering", specializations "Engineering, Computer Modeling and Design of Packaging Equipment", "Engineering, Computer Modeling and Design of Equipment for the Production of Polymer and Building Materials and Products". Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2018. 290 p. <https://ela.kpi.ua/handle/123456789/23917>
4. Karvatsky A. Ya. Mechanics of Continuum Media – 2. Nonlinear Problems of Mechanics of Continuum Media. Practical Course on the Discipline [Electronic Resource]: Teaching Aids for Students of Specialty 133 "Industrial Mechanical Engineering", specializations "Engineering, Computer Modeling and Design of Equipment for the Production of Polymer and Building Materials and Products". Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2018. 390 p. <https://ela.kpi.ua/handle/123456789/23918>
5. Karvatsky A. Ya. Nonlinear problems of mechanics of continua. Computer practical course on the academic discipline [Electronic resource]: teaching aids for students of specialty 133 "Industrial mechanical engineering", specialization "Engineering, computer modeling and design of equipment for the production of polymer and building materials and products". Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2019. 158 p. <https://ela.kpi.ua/handle/123456789/27528>

Additional literature

1. Website: Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities. URL: <http://gmsh.info/>
2. Website: ParaView. An open-source, multi-platform data analysis and visualization application. URL: <https://www.paraview.org/>
3. Zienkiewicz, O., Taylor, R., Fox, D.: The Finite Element Method for Solid and Structural Mechanics. 7th edn. Elsevier Ltd., Oxford (2014).
4. Mase G. E. Theory and Problems of Continuum Mechanics. New York: McGraw-Hill Book Company. 1970. 230 p. URL : <https://www.twirpx.com/file/897819/>

5. Thompson, M., Thompson, J.: ANSYS Mechanical APDL for Finite Element Analysis, 1st edn. Butterworth-Heinemann, Oxford (2017).
6. Theoretical and experimental studies of the thermoelectric and mechanical state of high-temperature units: monograph. / A. Ya. Karvatsky, E. M. Panov, S. V. Kutuzov and others. Kyiv: NTUU "KPI", 2012. 352 p. <https://ela.kpi.ua/handle/123456789/4718>
7. Regularities of the process of high-temperature processing of bulk carbon materials in electric furnaces: monograph / T. V. Lazarev, A. Ya. Karvatsky, E. M. Panov, S. V. Leleka, A. Yu. Pedchenko. Kyiv: NTUU "KPI" Publishing House "Polytechnics", 2016. 156 p. URL : <https://ela.kpi.ua/handle/123456789/15217>
8. Theoretical and experimental studies of Kastner graphitization furnaces: monograph / A. Yu. Pedchenko, E. M. Panov, A. Ya. Karvatsky, S. V. Leleka, T. V. Lazarev. Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2017. 174 p. URL : <http://ela.kpi.ua/handle/123456789/20800>
9. Energy-resource-efficient production of isostatic graphite: monograph / E. M. Panov, S. V. Leleka, A. Ya. Karvatsky, I. O. Mikulyonok. Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2020. 140 p. ISBN 978-617-7734-26-9 URL : <https://ela.kpi.ua/handle/123456789/37590>
10. Energy-resource-efficient pressing of carbon-graphite products: monograph / E. M. Panov, S. V. Leleka, A. Ya. Karvatsky, I. O. Mikulyonok. Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2020. 84 p. ISBN 978-617-7734-27-6 URL : <https://ela.kpi.ua/handle/123456789/37591>
11. An Introduction to Granular Flow / K. Kesava Rao, Prabhu R. Nott. New York: Publ. in the USA by Cambridge University Press, 2008. 490 p.
12. Poinot T., Veynante D. Theoretical and numerical combustion. 2nd ed. Philadelphia : Edwards, 2005. 522 p.
13. Website: OpenFOAM. Open Source Field Operation And Manipulation CFD ToolBox – an open integrated platform for numerical modeling of continuum mechanics problems URL: <http://www.openfoam.com/>
14. Website: LIGGGHTS Open Source Discrete Element Method Particle Simulation Code. URL: <https://www.cfdem.com/>
15. Patankar, S.V.: Numerical Heat Transfer and Fluid Flow (Hemisphere Series on Computational Methods in Mechanics and Thermal science). 1st edn. McGraw-Hill Book Company, New York (1980). DOI: 10.1201/9781482234213
16. Mathcad: Math software for your engineering calculations. URL: <https://www.mathcad.com/en>
17. Karvatsky A. Ya. Finite element method in problems of mechanics of continuums. Software implementation and visualization of results: teaching aids. manual. Kyiv: NTUU "KPI" VPI VPK "Polytechnics", 2015. 392 p. <http://ela.kpi.ua/handle/123456789/11636>
18. Modeling of statics and dynamics of loose materials in LIGGGHTS [Electronic resource]: manual for master's degree applicants in specialties 131 Applied Mechanics, 133 Industrial Mechanical Engineering / A. Ya. Karvatsky, I. O. Mikulyonok, V. M. Vytvytsky; Igor Sikorsky Kyiv Polytechnic Institute. – Electronic text data (1 file: 4.16 MB). – Kyiv: Igor Sikorsky Kyiv Polytechnic Institute, 2021. 76 p. <https://ela.kpi.ua/handle/123456789/45613>

Information resources on the Internet

1. DSpace STL Igor Sikorsky Kyiv Polytechnic Institute, <https://ela.kpi.ua/handle/123456789/19011>, <http://ela.kpi.ua/handle/123456789/23916>, <https://ela.kpi.ua/handle/123456789/23917>, <https://ela.kpi.ua/handle/123456789/23918>, <https://ela.kpi.ua/handle/123456789/27528>, <http://ela.kpi.ua/handle/123456789/11636>, <https://ela.kpi.ua/handle/123456789/4718>, <https://ela.kpi.ua/handle/123456789/15217>, <http://ela.kpi.ua/handle/123456789/20800>, <https://ela.kpi.ua/handle/123456789/37590>, <https://ela.kpi.ua/handle/123456789/37591>
2. Website: Department of Chemical, Polymeric and Silicate Engineering, <http://cpsm.kpi.ua/mr.html>
3. Campus Igor Sikorsky Kyiv Polytechnic Institute, <http://login.kpi.ua/>
4. Distance learning platform "Sikorsky", <https://sikorsky-distance.kpi.ua/>

5. Methodology for mastering the educational component

Lecture classes

Lectures are aimed at:

- providing modern, holistic, interdependent knowledge on the educational component "Mechanics of Continuum", the level of which is determined by the target setting for each specific topic;
- ensuring creative work of students together with the teacher during the lecture;
- educating students in professional and business qualities and developing their independent creative thinking;
- forming the necessary interest in students and providing a direction for independent work;
- determining the current level of development of science in the field of modern methods of mechanics of continua;
- reflecting the methodological processing of the material (highlighting the main provisions, conclusions, recommendations, clear and adequate formulation of them);
- using visual materials for demonstration, combining them, if possible, with the demonstration of calculation results;
- teaching materials of the educational component in a clear and high-quality language with observance of structural and logical connections, explanation of all newly introduced terms and concepts;
- accessibility for perception by a given audience.

No s/p	The name of the lecture topic and the list of main issues (links to literature and tasks on the IWS)	Number of hours
Section 1. Mechanics of continuum (MC) in engineering calculations		
1	Topic 1. Subject of the MC. Properties of continuous media <u>Lecture 1.</u> Definition of MC. Axiomatics of continuum mechanics. Main methods and directions of research of various MC objects (solids, liquids and gases). Connection of the course with other educational components (resistance of materials, hydraulics, thermodynamics, computational mathematics, programming, technological calculations and calculations for the strength of machines and devices). General characteristics of physical phenomena and processes occurring in solids, liquids and gases. Physical models of MC. Laws of thermodynamics. <u>List of didactic aids:</u> The lecture uses a laptop with an electronic version of the lecture and a projector. Drawings, posters for the lecture. <u>Tasks for the IWS.</u> General methods of research of continua in their interaction with each other and with force, temperature, radiation, electromagnetic fields. Saint-Venant's principle. Repetition of course materials theoretical foundations of heat engineering. <u>Literature:</u> electronic lecture notes [1], pp. 15–21. Topic 2. Basic concepts, definitions and hypotheses of the MC. The concept of continuum. Lagrangian and Euler coordinates for describing the motion of bodies, substantial derivative with respect to time. Vector bases in the initial and current configuration of bodies. MC hypotheses and their role in the development of mathematical models. Problems of continuum mechanics. Mutual dependence between Lagrangian and Euler coordinates. Orthotropic, anisotropic and transversely isotropic bodies. External mass and surface forces. Internal forces (efforts). <u>Literature:</u> electronic lecture notes [1], pp. 22–31; [A4]: section 1, § 2, pp. 15–21, section 2, § 1–3, pp. 22–34.	3
2	Topic 3. Introduction to Tensor Analysis <u>Lecture 2.</u> The concept of a vector. Coordinate systems. Representation of vectors in rectangular and oblique rectilinear coordinates. Basic and reciprocal	3

No s/p	The name of the lecture topic and the list of main issues (links to literature and tasks on the IWS)	Number of hours
	vector bases. Properties of the mixed product of vectors. Silent, free, covariant and contravariant indices. Covariant and contravariant components of a vector. Actions on vectors. Definition of a tensor. Representation of tensors through vectors of the basic and reciprocal bases, vector support. Fundamental tensors of coordinate systems: metric, coordinate transformation, Levi-Civita. Components of the metric tensor. Components of the coordinate transformation tensor. <u>List of didactic aids:</u> The lecture uses a laptop with an electronic version of the lecture and a projector. Drawings, posters for the lecture. <u>Tasks on the IWS.</u> Formulas for transforming vector components when moving from the basic to the reciprocal basis and vice versa. <u>Literature:</u> electronic lecture notes [1], p. 31–37; [A4]: chapter 2, § 3–8, pp. 34–97. Properties of the components of the metric tensor. Dependencies between covariant and contravariant components of the metric tensor. Symmetry of stress and strain tensors. Literature: electronic lecture notes [1], pp. 37–42; [A4]: chapter 2, § 4–7, pp. 47–107.	
3	<u>Lecture 3.</u> Components of the Levi-Civita tensor. Unary operations on a tensor: transpose, scalar convolution, vector convolution, tensor trace. Binary operations with tensors: sum of tensors, scalar product, double scalar product, vector product, tensor product. Differentiation of tensors. Hamilton operator. Tensor gradient. Divergence operator. Rotor. Curvilinear coordinates. Differentiation of tensors in curvilinear coordinates. Properties of Christoffel symbols. Covariant derivatives of a 2nd rank tensor given by contravariant components. Differentiation of a tensor given by covariant components. <u>List of didactic aids:</u> A laptop with an electronic version of the lecture and a projector are used in the lecture. Drawings, posters for the lecture. <u>Tasks for the IWS.</u> The Levi-Civita tensor and its properties. Formulas for the components of the cross product of tensors based on the Levi-Civita tensor. <u>Literature:</u> Elek. lecture notes [1]. Topic 4. Theory of stresses in a continuous medium. Section principle for determining internal forces. Stress vector, average stresses and stresses at a point of the body. Normal and tangential stresses. Thermal stresses. Determination of stresses on an inclined plane. Notation of stresses on coordinate planes and rules of signs for them. Regularities of stress changes during rotations of the coordinate system. Main invariants of the stress tensor. Determination of maximum tangential stresses and orientation of the planes on which they act. <u>Literature:</u> electronic lecture notes [1], pp. 48–53; pp. 143–153; [A4]: section 2, § 2.1–2.14, pp. 68–87. electronic lecture notes [1], pp. 42–48; [A11]: appendices A–J, pp. 403–458.	3
4	<u>Lecture 4.</u> Covariant derivatives of mixed components of tensors. Transformation of components of fundamental tensors and Christoffel symbols when changing the coordinate system. Scalar product of any tensor to a metric tensor. Relationship between metric tensors and Christoffel symbols. Christoffel symbols of the 1st kind. Physical components of tensors. Material or tensor derivative. Invariant form of writing equations. <u>List of didactic aids:</u> The lecture uses a laptop with an electronic version of the lecture and a projector. Drawings, posters for the lecture. <u>Tasks for the IWS.</u> Topic 5. Types of stress state of a continuous medium. Examples of stress states. Mohr's circles. Centrosymmetric, plane and axisymmetric stress state. Differential equations of statics and dynamics in cylindrical coordinates. <u>Literature:</u> electronic lecture notes [1], pp. 54–61; pp.	3

No s/p	The name of the lecture topic and the list of main issues (links to literature and tasks on the IWS)	Number of hours
	153–166. Topic 7. Physical equations of a homogeneous medium. <i>Physical equations of state. Physical laws for solids. Deviator of deformation and stresses. Isotropic, orthotropic and anisotropic materials. Representation of physical equations of state in tensor form. Tensor of the 4th rank of physical constants. Properties of components of tensors of the 4th rank of physical (elastic) constants. Transition from one coordinate system to another. Relationship between stress and strain rate for liquids and gases. Navier-Stokes law. Deviator and average stresses in a liquid.</i> Topic 6. Theory of deformations of a continuous medium. <i>Initial and current state of the medium. Vectors of displacements and velocities. Gradients of displacements and velocities. Linear geometric equations. Dependencies between linear deformations, rotation vector and displacements. Principal deformations and principal directions. Geometric equations for finite deformations. Logarithmic measure of deformations. Deformation rates. Temperature deformations. Formulas for transforming components of deformation tensors and deformation rates. Representation of finite deformations through a linear deformation tensor and a linear rotation vector. Literature: electronic lecture notes [1], pp. 62–67; pp. 166–176. [A4]: section 3, § 3.1–3.16, pp. 112–155.</i>	
5	Topic 8. Laws of conservation of the continuous medium <i>Lecture 5. Ostrogradsky-Gauss formula. Divergence theorem. Basic equations of continuum mechanics. Law of conservation of mass. Derivation of the continuity equation. Invariant form of the mass conservation equation. Form of writing the continuity equation in the Euler and Lagrangian coordinate systems. . Equations of motion. Forms of writing the differential equation of motion. Equilibrium equations and stress tensors in Lagrangian variables. Piola and Cauchy-Euler tensors.</i> <i>List of didactic aids: The lecture uses a laptop with an electronic version of the lecture and a projector. Drawings, posters for the lecture.</i> <i>Tasks for the IWS. Topic 7. Physical equations of a homogeneous medium.</i> Elastic, elastically hereditary solid deformable bodies. Hooke's, Genka's, Signorina's laws. Elastically nonlinear, elastically plastic solids. Elastic deformation energy. Total potential energy of a body. Literature: electronic lecture notes [1], pp. 67–72; pp. 176–182. [A4]: section 6, 10, § 1–4, pp. 410–461. Topic 7. Physical equations of a homogeneous medium. Deformation theory of plasticity and theory of plastic flow. Creep of solids. Theory of small elastic-plastic deformations. Literature: electronic lecture notes [1], pp. 72–78, pp. 182–190; [A4]: section 9, § 9.1–9.8, pp. 279–308.	3
6	<i>Lecture 6. External forces on the surface of a body. The relationship between the stress tensor and the stress vector. Normal force and stress on the surface. Tangential stress on the surface. D'Alembert's principle. The law of conservation of momentum (momentum). Momentum, momentum. The law of conservation of mechanical energy. Operators of the double (multiple) scalar product of two tensors. Symmetry of stress tensors.</i> <i>List of didactic aids: The lecture uses a laptop with an electronic version of the lecture and a projector. Drawings, posters for the lecture.</i> <i>Tasks for the IWS. Topic 7. Physical equations of a homogeneous medium.</i> Physical equations for viscous compressible fluids. Stokes' law. Physical equations for viscous incompressible fluids. Literature: electronic lecture notes [1], pp. 79–83; pp. 190–191. Laws of conservation of mass and momentum in the MCC. Dissipative function. The equation of connection between	3

No s/p	The name of the lecture topic and the list of main issues (links to literature and tasks on the IWS)	Number of hours
	<i>thermodynamic potentials. <u>Literature</u>: electronic lecture notes [1], pp. 83–88; pp. 191–194.</i>	
7	<u>Lecture 7.</u> The law of conservation of total energy. Heat capacity. The law of entropy balance. The second law of thermodynamics. Heat conduction equations. The main system of equations of the MC. Physical equations of state. Geometric equations. Fourier's law. Heat conduction equations. Geometric Cauchy equations. Deformation rates. Topic 9. Solving equations of the MC in Cartesian and curvilinear coordinates. Fundamentals of formulating problems of mechanics of continuous media in Cartesian coordinates. Geometric equations. Physical equations. Equations of equilibrium, energy, deformation and the physical equation relative to components. Equations of equilibrium, energy and Hooke's law in the Cartesian coordinate system. <u>List of didactic aids:</u> The lecture uses a laptop with an electronic version of the lecture and a projector. Drawings, posters for the lecture. <u>Tasks for the IWS.</u> Contact, convective and radiative conditions of heat exchange with the external environment. <u>Literature</u>: electronic lecture notes [1], pp. 88–94; pp. 194–196. Two-dimensional problems of continuum mechanics. Hypotheses and equations of plane and axisymmetric problems. <u>Literature</u>: electronic lecture notes [1], pp. 95–101; pp. 197–206; [A4]: section 6, § 6.1–6.8, pp. 207–212.	4
8	<u>Lecture 8.</u> Construction of equations of mechanics of continuous media in curvilinear coordinates. Determination of geometric characteristics of a cylindrical coordinate system. Determination of basis vectors of a cylindrical coordinate system. Determination of components of fundamental tensors. Components of the Levi-Civita tensor. Components of the coordinate transformation tensor. Relationship between components of coordinate transformation tensors. Definition of Christoffel symbols. Recording of the gradient of displacements and stresses through Christoffel symbols. Equilibrium equations in a cylindrical coordinate system. <u>List of didactic aids:</u> The lecture uses a laptop with an electronic version of the lecture and a projector. Drawings, posters for the lecture. <u>Tasks on the IWS.</u> Quasistatic equations of thermoviscoelasticity. Boundary conditions. <u>Literature</u>: electronic lecture notes [1], pp. 101–107; pp. 206–210; [A4]: chapter 9, § 9.1–9.8, pp. 279–306. The difference between the non-rheological theory of plasticity and the theory of visco-plasticity. <u>Literature</u>: electronic lecture notes [1], pp. 107–111; pp. 210–211; [A4]: chapter 9, § 9.1–9.8, pp. 279–306.	4
9	<u>Lecture 9.</u> Basic equations of MC for liquids and gases. Lagrangian and Euler coordinate systems. Equations of motion in different reference frames. Obtaining the invariant form of the equation of motion. The mass conservation equation in different reference frames. Obtaining the invariant form of the mass conservation equation. The energy conservation equation in different reference frames. Invariant form of the energy conservation equation. Coupled equations of linear thermo-elasticity. Initial and boundary conditions. Thermo-plasticity equations. Initial and boundary conditions. <u>List of didactic aids:</u> The lecture uses a laptop with an electronic version of the lecture and a projector. Drawings, posters for the lecture. <u>Tasks for the IWS.</u> Solving equations of thermo-visco-elasticity. <u>Literature</u>: electronic lecture notes [1], pp. 111–117; pp. 211–214; [A4]: section 7, § 7.1–7.6, pp. 228–247. Determination of state parameters of polymers for non-	4

No s/p	The name of the lecture topic and the list of main issues (links to literature and tasks on the IWS)	Number of hours
	<i>isothermal processes. Literature: electronic lecture notes [1], pp. 117–123; pp. 214–217; [A4]: section 8, § 8.1–8.11, pp. 248–276.</i>	
<i>Total</i>		30

Practical classes

The main goals of the cycle of practical classes (computer workshops) are to enable students to apply theoretical knowledge to solve practical problems in continuum mechanics [4], to acquire the ability to use CAD systems Gmsh [A1] and Mathcad [8] and freely open source software OpenFOAM [A13] and LIGGGHTS [A14] to build complex numerical models of assemblies and parts of industrial equipment, visualization using the ParaView viewer [A2], and analysis of the obtained results of calculations of physical fields during the design or modernization of machines and devices in the chemical industry.

No s/p	The name of the topic of practical classes and the list of main issues (reference to literature and tasks on the IWS)	Number of hours
1	Topic 1. Static elasticity and uncoupled thermo-elasticity. Problems of the plane-deformed state (PDS) and the plane-stressed state (PSS) Computer workshop No. 1. Solving the problem of plane-deformed state on the example of bending of a cantilever beam by the finite element method (FEM) using triangular finite elements in the Mathcad environment. <u>Literature:</u> [2], pp. 9–12, pp. 87–127. <u>List of didactic tools:</u> personal computer, Mathcad, ParaView software products, examples of program codes for solving PDS, PSS problems. <u>Tasks on the IWS.</u> Determination of the structural safety margin. Methods of analyzing the accuracy and reliability of the obtained results. Determination of the convergence of solutions by the method of double calculations. <u>Literature:</u> [2], pp. 18, pp. 32, pp. 87–127, pp. 149–168, pp. 193–197, pp. 296–312. Examples of solving problems of continuum mechanics. Introduction to tensor calculus. References: [4], pp. 10–50.	2
2	Topic 2. Static elasticity. Axisymmetric stress-strain problem Computer workshop No. 2. Calculation of the flange for strength in an axisymmetric formulation by the FEM method using triangular finite elements in the Mathcad environment. <u>Literature:</u> [2], p. 13–14, p. 87–127, p. 149–168, p. 198–195. <u>List of didactic tools:</u> personal computer, Mathcad, ParaView software products, examples of program codes for solving an axisymmetric problem of the stress-strain state. <u>Tasks on the IWS.</u> Determination of the safety margin of the structure. Determination of the convergence of solutions by the method of double calculations. <u>Literature:</u> [2], p. 18, p. 32, p. 87–127, p. 313–331. Examples of solving problems of continuum mechanics. Stressed state. <u>Literature:</u> [4], p. 54–92.	2
3	Topic 3. Steady-state thermal conductivity with an internal heat source Computer workshop No. 3. Solution of a three-dimensional heat conduction problem using the example of calculating a flange by the FEM method using finite elements in the form of tetrahedra in the Mathcad environment. <u>Literature:</u> [2], p. 8, p. 23–84, p. 149–168, p. 170–191. <u>List of didactic tools:</u> personal computer, software products Gmsh, Mathcad, ParaView, examples of program codes for solving a three-dimensional heat conduction problem. <u>Tasks on the IWS.</u> Determination of the convergence of solutions by the method	2

No s/p	The name of the topic of practical classes and the list of main issues (reference to literature and tasks on the IWS)	Number of hours
	of double calculations. <u>Literature</u> : [2], p. 23–84, p. 184–191, p. 277–295. Examples of solving problems of continuum mechanics. Deformed state. <u>Literature</u> : [4], p. 95–134.	
4	Topic 4. Stress-strain state of a flat hinged truss Computer workshop No. 4. Solving the problem of the stress-strain state of a plane hinged truss by the FEM method using one-dimensional finite elements in the Mathcad environment. <u>Literature</u> : [2], pp. 87–127. <u>List of didactic tools</u> : personal computer, Mathcad, ParaView software products, examples of program codes for solving the problem of the stress-strain state. <u>Tasks on the IWS</u> . Determination of the safety margin of the structure. <u>Literature</u> : [2], pp. 32, pp. 87–127, pp. 362–372. Examples of solving problems of continuum mechanics. Motion and flow. <u>Literature</u> : [4], pp. 138–170.	2
5	Topic 5. Static elasticity. Three-dimensional problem of linear static elasticity Computer workshop No. 5. Solution of a three-dimensional static elasticity problem using the example of calculating a flange for strength by the MFE method using finite elements in the form of tetrahedra in the Mathcad environment. <u>Literature</u> : [2], pp. 15–17, pp. 87–127, pp. 332–361. <u>List of didactic tools</u> : personal computer, software products Gmsh, Mathcad, ParaView, examples of program codes for solving a three-dimensional linear elasticity problem. <u>Tasks on the IWS</u> . Determination of the safety margin of the structure. Determination of the convergence of solutions by the method of double calculations. <u>Literature</u> : [2], pp. 18, pp. 32, pp. 332–361. Examples of solving problems of continuum mechanics. Basic laws of continuum mechanics. <u>Literature</u> : [4], pp. 172–187.	2
6	Topic 6. Fluid mechanics. The problem of steady flow of an incompressible fluid Computer workshop No. 6. Solution of the axisymmetric steady flow problem of an incompressible fluid (based on the Stokes equation system) in a cylindrical channel by the MFE method using triangular finite elements in the Mathcad environment. <u>Literature</u> : [2], p. 19–20, p. 218–222, p. 373–385. <u>List of didactic tools</u> : personal computer, software products Gmsh, Mathcad, ParaView, examples of program codes for solving the axisymmetric steady flow problem of an incompressible fluid. <u>Tasks on the IWS</u> . Determination of pressure and velocity fields. Determination of convergence of solutions by the method of double calculations. <u>Literature</u> : [2], p. 32, p. 373–385. Examples of solving problems of continuum mechanics. Mechanics of liquids and gases. <u>Literature</u> : [4], pp. 222–250.	2
7	Modular control work	2
Total		14

Seminar classes

The working curriculum does not include seminar classes.

Laboratory classes

The working curriculum does not include laboratory classes.

6. Student independent work

No s/p	Name of the topic submitted for self-study	Number of hours of IWS
1	Topic 1. The subject mechanics of continuum (MC). Properties of continuum media <i>General methods of studying continuous media in their interaction with each other and with force, temperature, radiation, electromagnetic fields. Saint-Venant's principle. Review of materials of the course Theoretical foundations of heat engineering. Literature: electronic lecture notes [1], p. 15–21.</i> <i>Solving the problem of plane-stressed state on the example of bending of a cantilever beam by the finite element method (FEM) using triangular finite elements in the Mathcad environment. Literature: [2], p. 9–12, p. 87–127.</i>	7
2	Topic 2. Basic concepts, definitions and hypotheses of the MC <i>Mutual dependences between Lagrangian and Eulerian coordinates. Orthotropic, anisotropic and transversely isotropic bodies. External mass and surface forces. Internal forces (efforts). Literature: electronic lecture notes [1], pp. 22–31.</i> <i>Determination of the safety margin of a structure. Methods of analyzing the accuracy and reliability of the obtained results. Determination of the convergence of solutions by the method of double calculations. Literature: [2], pp. 18, pp. 32, pp. 87–127, pp. 149–168, pp. 193–197, pp. 296–312.</i>	7
3	Topic 3. Introduction to Tensor Analysis <i>Formulas for transforming vector components when moving from the main to the reciprocal basis and vice versa. Literature: electronic lecture notes [1], pp. 31–37.</i> <i>Properties of metric tensor components. Dependencies between covariant and contravariant components of the metric tensor. Symmetry of stress and strain tensors. Literature: electronic lecture notes [1], pp. 37–42.</i> <i>Levi-Civita tensor and its properties. Formulas for components of the vector product of tensors based on the Levi-Civita tensor. Literature: electronic lecture notes [1], pp. 42–48; [A11]: appendices A–J, pp. 403–458.</i> <i>Calculation of flange strength in an axisymmetric formulation by the MFE method using triangular finite elements in the Mathcad environment. Literature: [2], pp. 13–14, p. 87–127, p. 149–168, p. 198–195.</i>	7
4	Topic 4. Theory of stresses in a continuous medium <i>The principle of the section for determining internal forces. Stress vector, average stresses and stresses at a point of the body. Normal and tangential stresses. Thermal stresses. Determination of stresses on an inclined plane. Notation of stresses on coordinate planes and rules of signs for them. Regularities of stress changes during rotations of the coordinate system. Main invariants of the stress tensor. Determination of maximum tangential stresses and orientation of the planes on which they act. Literature: electronic lecture notes [1], pp. 48–53; pp. 143–153; [A4]: section 2, § 2.1–2.14, pp. 68–87.</i> <i>Determination of the safety margin of a structure. Determination of the convergence of solutions by the method of double calculations. Literature: [2], pp. 18, pp. 32, pp. 87–127, pp. 313–331.</i> <i>Examples of solving problems of continuum mechanics. Stressed state. Literature: [4], pp. 54–92.</i>	7
5	Topic 5. Types of stress state of a continuous medium <i>Examples of stress states. Mohr circles. Centrosymmetric, plane and axisymmetric stress state. Differential equations of statics and dynamics in cylindrical coordinates. Literature: electronic lecture notes [1], pp. 54–61; pp. 153–166.</i>	9

No s/p	Name of the topic submitted for self-study	Number of hours of IWS
	<i>Solution of a three-dimensional heat conduction problem using the example of a flange calculation by the MFE method using finite elements in the form of tetrahedra in the Mathcad environment. Literature: [2], pp. 8, pp. 23–84, pp. 149–168, pp. 170–191.</i> <i>Determination of the convergence of solutions by the method of double calculations. Literature: [2], pp. 23–84, pp. 184–191, pp. 277–295.</i> <i>Examples of solving problems of continuum mechanics. Deformed state. Literature: [4], pp. 95–134.</i>	
6	Topic 6. Theory of deformations of a continuous medium <i>Initial and current state of the environment. Vectors of displacements and velocities. Gradients of displacements and velocities. Linear geometric equations. Dependencies between linear deformations, rotation vector and displacements. Principal deformations and principal directions. Geometric equations for finite deformations. Logarithmic measure of deformations. Deformation rates. Temperature deformations. Formulas for transforming components of deformation tensors and deformation rates. Representation of finite deformations through a linear deformation tensor and a linear rotation vector. Literature: electronic lecture notes [1], pp. 62–67; pp. 166–176. [A4]: section 3, § 3.1–3.16, pp. 112–155.</i> <i>Solution of a three-dimensional problem of static elasticity on the example of calculating a flange for strength by the MSE method using finite elements in the form of tetrahedra in the Mathcad environment. Literature: [2], pp. 15–17, pp. 87–127, pp. 332–361.</i> <i>Determination of the safety margin of a structure. Determination of the convergence of solutions by the method of double calculations. Literature: [2], pp. 18, pp. 32, pp. 332–361.</i> <i>Examples of solving problems of continuum mechanics. Basic laws of continuum mechanics. Literature: [4], pp. 172–187.</i>	9
7	Topic 7. Physical equations of a homogeneous medium <i>Physical equations of state. Physical laws for solids. Deviator of deformation and stresses. Isotropic, orthotropic and anisotropic materials. Representation of physical equations of state in tensor form. Tensor of the 4th rank of physical constants. Properties of components of tensors of the 4th rank of physical (elastic) constants. Transition from one coordinate system to another. Relationship between stress and strain rate for liquids and gases. Navier-Stokes law. Deviator and average stresses in a liquid. Elastic, elastically hereditary solid deformable bodies. Hooke's, Genka's, Signorini's laws. Elastically nonlinear, elastically plastic solids. Energy of elastic deformation. Total potential energy of a body. Literature: electronic lecture notes [1], pp. 67–72; pp. 176–182.</i> <i>Deformation theory of plasticity and theory of plastic flow. Creep of solids. Theory of small elastic-plastic deformations. Literature: electronic lecture notes [1], pp. 72–78, pp. 182–190; [A4]: section 9, § 9.1–9.8, pp. 279–308.</i>	10
8	Topic 8. Laws of conservation of a continuous medium <i>Ostrogradsky-Gauss formula. Divergence theorem. Basic equations of continuum mechanics. Law of conservation of mass. Derivation of the continuity equation. Invariant form of the mass conservation equation. Form of writing the continuity equation in the Euler and Lagrangian coordinate systems. Equations of motion. Forms of writing the differential equation of motion. Equations of equilibrium and stress tensors in Lagrangian variables. Piola and Cauchy-Euler tensors. Laws of</i>	9

No s/p	Name of the topic submitted for self-study	Number of hours of IWS
	conservation of mass and momentum in the MCC. Dissipative function. Equation of connection between thermodynamic potentials. <u>Literature</u>: electronic lecture notes [1], pp. 83–88; pp. 191–194. Contact, convective and radiative conditions of heat exchange with the external environment. <u>Literature</u>: electronic lecture notes [1], pp. 88–94; pp. 194–196. Solution of the axisymmetric steady flow problem of an incompressible fluid (based on the Stokes equation system) in a cylindrical channel by the MSE method using triangular finite elements in the Mathcad environment. <u>Literature</u>: [2], pp. 19–20, pp. 218–222, pp. 373–385. Determination of pressure and velocity fields. Determination of convergence of solutions by the method of double calculations. <u>Literature</u>: [2], pp. 32, pp. 373–385. Examples of solving problems of continuum mechanics. Mechanics of liquids and gases. <u>Literature</u>: [4], pp. 222–250.	
9	Topic 9. Solving MCC equations in Cartesian and curvilinear coordinates Two-dimensional problems of continuum mechanics. Hypotheses and equations of plane and axisymmetric problems. <u>Literature</u>: electronic lecture notes [1], pp. 95–101; pp. 197–206; [A4]: section 6, § 6.1–6.8, pp. 207–212. Quasistatic equations of thermoviscoelasticity. Boundary conditions. <u>Literature</u>: electronic lecture notes [1], pp. 101–107; pp. 206–210; [A4]: section 9, § 9.1–9.8, pp. 279–306. The difference between the non-rheological theory of plasticity and the theory of viscoplasticity. <u>Literature</u>: electronic lecture notes [1], pp. 107–111; pp. 210–211; [A4]: section 9, § 9.1–9.8, pp. 279–306. Determination of state parameters of polymers for non-isothermal processes. <u>Literature</u>: electronic lecture notes [1], pp. 117–123; pp. 214–217; [A4]: section 8, § 8.1–8.11, pp. 248–276.	7
10	Modular control work	4
11	Exam	30
Total		106

Individual tasks

The working curriculum does not provide for individual assignments.

Control works

The purpose of the modular test:

- a summary of the study of the topics of the credit module;
- application of the acquired knowledge to perform engineering calculations;
- the ability to independently apply the acquired knowledge to perform tasks in this credit module and in other educational components: “Packaging equipment”, “CAD of technological equipment”, “Research and engineering of packaging equipment. Course project”, “Scientific work on the topic of the master's thesis”.

The curriculum of the educational component provides for one modular test, which covers sections 1 and 2. An approximate list of questions for the MCW is given at the end of the Syllabus. The formulation of questions for the MCW may be slightly changed in accordance with the features of teaching the lecture material and its perception by students. In order to prepare students in the ICW mode, the teacher familiarizes them with questions for the MCR 1–2 weeks before performing the work. A package of tasks for the MCW has been developed.

7. Educational component policy

Rules for attending classes and behavior in classes

Attending classes is a mandatory component of assessment. Students are obliged to take an active part in the educational process, not to be late for classes and not to miss them without a good reason, not to interfere with the teacher to conduct classes, not to be distracted by actions that are not related to the educational process.

Rules for the implementation and protection of practical work (computer workshops):

- practical work (computer workshops) takes place during hours of practical classes and SRS and is sent to the teacher's e-mail or telegrams;
- practical work (computer workshops) takes place during hours of practical classes and SRS and is sent to the teacher's e-mail or telegrams;
- rules for the protection of practical works (computer workshops) are based on a rating system for assessing learning outcomes.

Rules for assigning incentive and penalty points:

- encouraging points can be credited by the teacher for active participation in lectures, preparation of scientific publications on topics of the discipline. At the same time, the amount of incentive points may not exceed 25% of the rating scale.
- penalty points within the discipline are not provided.

Deadline and overlay policy

In case of debts in the discipline or any force majeure circumstances, students should contact the teacher through accessible (provided by the teacher) communication channels to solve problematic issues and coordinate the algorithm of actions for working out.

Academic Integrity Policy

Violation of the Code of Academic Integrity of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" is a serious violation, even if it is unintentional. The Code is available at the link: <https://kpi.ua/code.3>.

In particular, compliance with the Code of Academic Integrity means that all work in exams and tests must be performed individually. When doing independent work, students can consult with teachers and other students, but must independently solve problems, guided by their own knowledge, skills and abilities. References to all resources and sources (e.g. in reports from computer workshops, independent work or presentations) should be clearly defined and properly executed. That is, it is unacceptable to have no references when using printed and electronic materials, quotes, opinions of other authors.

Policy of academic behavior and ethics

Students should be tolerant, respect the opinion of others, object to formulate in the correct form, constructively maintain feedback in the classroom.

The norms of ethical behavior of students and employees are defined in Section 2 of the Code of Honor of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". More: <https://kpi.ua/code.2>.

1. Types of control and rating system for assessing learning outcomes (RS)

Distribution of educational time by types of classes and tasks from the credit module according to the working curriculum:

Semester	School time		Distribution of training hours				Control measures		
	credit	acad. h.	Lecture	Pract.	Ind.less.	IWS	MCW	HCW	Semester certification
1	5	150	30	14	–	106	1	–	Exam

Current control: express survey, reports from computer workshops, modular control work.

Calendar control: carried out twice a semester as a monitoring of the current status of implementation of the syllabus requirements.

Semester control: exam.

The student's rating in the discipline consists of points that he receives for:

- 1) express control;
- 2) completion of design and calculation tasks in practical classes (6 in total);
- 3) modular test;
- 4) answer to the exam (written).

System of rating (weight) points and evaluation criteria

1. Express control:

- “excellent”, complete answer (at least 90% of the required information) – 2 points;
- “satisfactory”, incomplete answer (at least 60% of the required information) and minor errors – 1 point;
- “unsatisfactory”, unsatisfactory answer (does not meet the requirements for 1 point) – 0 points.

2. Practical exercises:

- “excellent”, creative execution of the task, fluent mastery of the material – 4-5 points;
- “good”, execution of the task in full, but with minor errors – 3 points;
- “satisfactory”, execution of the task with individual errors – 2 points;
- “unsatisfactory”, failure to complete the task – 0 points.

3. Modular test:

- “excellent”, complete answer (at least 90% of the required information) – 10-12 points;
- “good”, sufficiently complete answer (at least 75% of the required information), or a complete answer with minor inaccuracies – 7-9 points;
- “satisfactory”, incomplete answer (at least 60% of the required information) and minor errors – 4-5 points;
- “unsatisfactory”, unsatisfactory answer – 0 points.

One or two best students in each practical session may be awarded 1-2 bonus points; +5 bonus points for a report on the results of studying the educational component at a student conference or publication in a journal.

The maximum sum of points for the starting component is 50. A prerequisite for admission to the exam is the completion of all practical session tasks and passing the module test and a starting rating of at least 25 points.

According to the results of the academic work in the first 7 weeks, the "ideal student" should score 25 points. At the certification (8th week), the student receives "passed" if his current rating is at least 12 points.

Based on the results of 15 weeks, the "ideal student" should score $r_c = 50$ points. At the second certification (week 14), the student receives "passed" if his current rating is at least 25 points.

The maximum amount of points for semester R is 50 (where $R = r_{e-kp} \cdot 4 + r_{pr} \cdot 6 + r_{mkr} = 2 \cdot 4 + 5 \cdot 6 + 12 = 8 + 30 + 12 = 50$).

At the exam, students complete a written test. Each task contains two theoretical questions and one practical one. The list of questions is given in the methodological recommendations for mastering the credit module. Each theoretical question is evaluated at 15 points, and the practical one is evaluated at 20 points.

Theoretical question grading system (r_{T1} , r_{T2}):

- “excellent”, complete answer (at least 90% of the required information) – 15-14 points;
- “good”, sufficiently complete answer (at least 75% of the required information or minor inaccuracies) – 13-11 points;
- “satisfactory”, incomplete answer (at least 60% of the required information and some errors) – 10-9 points;
- “unsatisfactory”, unsatisfactory answer – 0 points.

Practical assignment evaluation system (r_{pr}):

- “excellent”, complete error-free solution of the task (at least 90% of the required information) – 20-18 points;
- “good”, complete solution of the task with insignificant inaccuracies (at least 75% of the required information or minor inaccuracies) – 17-15 points;
- “satisfactory”, the task was completed with certain shortcomings (at least 60% of the required information and some errors) – 14-12 points;
- “unsatisfactory”, the task was not completed – 0 points.

The maximum rating for the examination test is

$$r_E = r_{T1} + r_{T2} + r_{pr} = 15 + 15 + 20 = 50 \text{ points.}$$

Admission requirements for semester examination: semester rating of at least 25 points.

The sum of the starting points and the points for the examination test is converted into the examination grade according to the table:

Table of correspondence of rating points to grades on the university scale:

Number of points	Estimation
100-95	Perfectly
94-85	Very good
84-75	Good
74-65	Satisfactory
64-60	Enough
Less 60	Unsatisfactorily
Admission conditions not met	Not allowed

9. Additional information on the educational component

List of questions submitted for semester control

Theoretical questions

1. Describe the MC and the axiomatics of the mechanics of continuum.
2. Analyze quasi-static equations of thermo-binding plasticity. Describe the appropriate boundary conditions.
3. Describe the related equations of linear thermo-elasticity. Analyze the initial and boundary conditions.
4. Describe the characteristics of the financial manifestations and processes that are in the solids, gases and gases. Describe the physics of MC models.
5. Analyze the concept of continuum. Describe the Lagrangian and Euler coordinates to describe the movement of bodies, a substance derivative of time.
6. Analyze the formulas for the vector product component of tensors based on the Levi-Civita tensor.

7. Analyze the properties of the metric strain gauge component. Write down and analyze the relationships between covariant and contravariant components of the metric strain gauge.
8. Characterize the vector basis in the cob and the actual conference.
9. Describe the hypotheses and describe their role in the development of mathematical models.
10. Prove the symmetry of tensors of stresses and deformations.
11. Describe the concept of vector, coordinate systems. Analyze the representation of vectors in rectangular and oblique straight coordinates.
12. Analyze the main invariants of the tension strain strain. Describe the definition of maximum tangent stresses and orientation of the planes on which they operate.
13. Analyze and compare and analyze the main and mutual vector bases. Describe the properties of mixed product vectors.
14. Describe the definition of the Levi-Civita strainer in orthogonal coordinate systems and its properties.
15. Describe the concepts of dumb, free, covariant and contravariant indices and give examples of their application.
16. Describe the principle of cross section to determine internal forces.
17. Describe the understanding of the insidious and contradictory components of the vector. Analyze your data over vectors.
18. Describe the concept of the vector of stress, average stress and tension at the point of the body. Analyze formulas for normal and tangent stresses on the plane.
19. Describe the definition of tensor. Analyze the representation of tensors through vectors of the main and mutual basis, vector support.
20. Describe the definition of stresses on the inclined plane. Analyze the designation of stresses on coordinate planes and the rules of signs for them.
21. Describe the fundamental strain gauges of coordinate systems: metric, coordinate conversion, Levi-Civita.
22. Analyze and compare the types of stress. Describe Mora's circles.
23. Analyze and compare the unary actions over the tensor: transpose, scalar convolution, vector convolution, tensor trail.
24. Analyze the patterns of changes in stresses when turning the coordinate system.
25. Analyze and compare binary operations with tensors: the sum of tensors, scalar product, double scalar product, vector product, tensor product.
26. Analyze the definition of centrosymmetric, flat and axisymmetric stress states and compare them.
27. Analyze and compare the differentiation of tensors in the curvilinear coordinate system with cartesian.
28. Analyze the representation of finite deformations through a linear deformation tensor and a linear rotation vector.
29. Analyze the differential equations of statics and dynamics in cylindrical coordinates and compare them with Cartesian.
30. Describe the concept of the tensor gradient, give examples of its application in the physical equations MC.
31. Describe the concept of the Hamilton operator, give examples of its application in MC equations.
32. Describe the energy of elastic deformation. Define the concept of full potential energy of the body.
33. Analyze and compare the operators of divergence and rotor, give examples of their application in MC equations.
34. Describe the temperature deformations.
35. Describe curvilinear coordinates.
36. Analyze geometric equations for finite deformations.
37. Describe the procedure for differentiating tensors in curvilinear coordinates.
38. Describe the laws of conservation of mass and the amount of movement in the MC.
39. Analyze the properties of Cristofell characters.
40. Describe the laws of Hooke, Genki, Sinyrini and compare them.

41. Analyze covariant derivatives from the tensor of the second rank given by the contravariant components.
42. Analyze and compare the properties of elastically nonlinear, elastic-plastic solids.
43. Analyze the procedure for differentiating the strainor given by covariant components.
44. Describe the concept of dissipative function. Determine the equation of the relationship between thermodynamic potentials.
45. Analyze the procedure for converting components of the fundamental tensors and symbols of Christoffels when changing the coordinate system.
46. Describe the physical equations of the state and the physical laws for solids.
47. Describe the ratio between tension and deformation rate for liquids and gases. Analyze the Navier-Stokes Law. Get formulas for deviator and medium stresses in the liquid.
48. Analyze the Ostrograd-Gaussian formula and describe its purpose. Describe the divergence theorem.
49. Analyze the formula of the scalar product of any tensor into a metric tensor.
50. Describe a material or tensor derivative.
51. Analyze the relationship between metric tensors and Christoffels characters. Define the concept of symbols of Christoffel of the 1st kind.
52. Analyze the basic equations of the mechanics of solid media.
53. Describe the law of conservation of mass. Perform the output of the incompressibility equation.
54. Describe the concept of logarithmic measure of deformations and deformation rate.
55. Analyze the system of thermoplastic equations. Analyze the appropriate initial and boundary conditions.
56. Describe the law of conservation of full energy.
57. Describe the basic MC equations for liquids and gases.
58. Analyze the equations of equilibrium, energy and Hooke's law in the Cartesian coordinate system.
59. Describe the equation of motion in different reference systems. Get an invariant form of the motion equation.
60. Analyze the procedure for determining the basic vectors of the cylindrical coordinate system.

Practical tasks

1. Solve the problem. If the flow of fluid occurs very slowly, so that the members of the order of the square of speed and above can be neglected, then we get a limit case, which is known as creeping motion. ($v_j v_{i,j} = 0$). To prove that in this case, with the established movement of the incompressible liquid at zero mass forces, the pressure is a harmonic function, that is, $\nabla^2 p = 0$.
2. Solve the problem. In the Cartesian coordinate system, the components of the tensor of stresses at the point are as follows: $\sigma^{11} = 12$, $\sigma^{12} = \sigma^{13} = 4$, $\sigma^{23} = 8$, $\sigma^{22} = \sigma^{33} = 0$. a) Identify the main stresses and main axes of the tension tensor. b) Spread the tensor of stresses by the sum of the ball tensor and deviator.
3. Solve the problem. Integrating Euler equations recorded for barotropic fluid flow at potential mass forces $\dot{v}_i = -(\Omega + P)_{,i}$, $\partial_e - \Omega_{,i} = b_i$, along the current lines get the equation

$$\Omega + P + \frac{v^2}{2} + \int \frac{\partial v_i}{\partial t} dx_i = C(t).$$
4. Solve the problem. Prove that in a non-viscous barotropic fluid with potential forces, the rate of circulation change is zero (Kelvin's theorem on the constancy of circulation).
5. Solve the problem. Write the incompressibility equation and the Navier-Stokes-Duham equation for dead-up motion due to the potential of speed φ .
6. The movement of the medium is called potential if there is a function such that $\mathbf{v} = \text{grad} \varphi$. Write an incompressibility equation for the potential motion of a compressive and incompressible medium in the form of an equation for potential φ in invariant form.

7. Solve the problem. For vectors $\mathbf{a} = 3\mathbf{i} + 4\mathbf{k}$, $\mathbf{b} = 2\mathbf{j} - 6\mathbf{k}$ and tiara $\mathbf{D} = 3\mathbf{i} + 2\mathbf{k} - 4\mathbf{j} - 5\mathbf{j}$ by multiplying the matrices to calculate the products $\mathbf{a} \cdot \mathbf{D}$, $\mathbf{D} \cdot \mathbf{b}$ i $\mathbf{a} \cdot \mathbf{D} \cdot \mathbf{b}$.
8. Solve the problem. On the horizontal rough surface of the plane moves at a constant speed of timber. The weight of the beam is equal to $P_z = 1 \text{ kN}$, $c \approx 10 \text{ H}$, The coefficient of friction of the coulomb on the plane is equal to $f_{\text{терт}} = 0,3$, the area of the base of the beam $S = 0,02 \text{ m}^2$. Find the vector of stress on the part of the plane that is currently under the beam.
9. Solve the problem. Vector V_i set in basis $\mathbf{a}, \mathbf{b}, \mathbf{c}$ its components $v_i = \alpha a_i + \beta b_i + \gamma c_i$. Show that
- $$\alpha = \frac{\varepsilon_{ijk} v_i b_j c_k}{\varepsilon_{pqr} a_p b_q c_r}.$$
10. Solve the problem. Find pressure function $P(p)$ with barotropic flow of liquid (Barotropic is the process in which $p = f(\rho)$) with the equation of indissolubility $p = \lambda \rho^k$, $\partial \lambda / \partial k$ – permanent.
11. Solve the problem. A wide container filled with incompressible liquid moves with constant acceleration $\vec{a} = a_2 \vec{e}_2 + a_3 \vec{e}_3$ in the field of gravity directed along the axis X_3 . Find the slope of the free surface of the liquid in the tank.
12. Solve the problem. Show Determinant

$$\det A_{ij} = \begin{vmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{vmatrix} \text{ can be written as } \varepsilon_{ijk} A_{1i} A_{2j} A_{3k}.$$

13. Solve the problem. Derive the equation of gas dynamics
- $$(\left(c^2 \delta_{ij} - v_i v_j \right) v_{j,i} = 0 \vee c^2 \nabla \cdot \mathbf{v} - \mathbf{v} \cdot (\mathbf{v} \cdot \nabla \mathbf{v}) = 0, \text{ where } c - \text{speed of sound in the medium, m/s})$$
- and write these equations through the speed potential Φ . The equation of gas dynamics is obtained for the established dead-up flow of compressed fluid by combining Euler's equations and indissolubility.
14. Solve the problem. Barotropic fluid is described by the equation of state $p = \lambda \rho^k$, where λ and k – permanent. The liquid is left alone in the field of gravity acting in the direction of X_3 . Find the pressure distribution depending on the X_3 , if the $X_3 = 0$ the pressure is equal to p_0 .
15. Solve the problem. Let the angles between the directions of the coordinate axes of the system with strokes and the system without strokes (see the previous task) be given in the following table:

	x_1	x_2	x_3
x'_1	135°	60°	120°
x'_2	90°	45°	45°
x'_3	45°	60°	120°

Define coordinate conversion strainer components C_{ij} and show that the conditions of orthogonality are met.

16. Solve the problem. Let atmospheric air be an ideal gas, the temperature of which varies linearly with height $T = T_0 + \alpha x_3$, where T_0 – temperature on the Earth's surface, and the coordinate x_3 it is counted from the earth's surface upwards. Determine atmospheric pressure as a function x_3 in hydrostatic conditions.
17. Solve the problem. The two-dimensional current is parallel to the plane $x_1 x_2$, speed component V_3 and $\frac{\partial V_3}{\partial x_3}$ zero. Write for this case the Navier-Stokes equation and the indissolubility equation of the incompressible liquid.

18. Solve the problem. Axes of cartesian coordinate system $Ox'_1x'_2x'_3$ obtained by turning the system $Ox_1x_2x_3$ per corner θ around the axis x_3 . Define conversion coefficients c_{ij} (conversion tensor) of the specified axes and find the components of the vector $\mathbf{v} = v_1\mathbf{e}_1 + v_2\mathbf{e}_2 + v_3\mathbf{e}_3$ in the system $Ox'_1x'_2x'_3$.
19. Solve the problem. In three-dimensional space, calculate the following expressions containing the Kronecker symbol δ_{ij} : a) δ_{ii} ; b) $\delta_{ij}\delta_{ij}$; c) $\delta_{ij}\delta_{ik}\delta_{jk}$; d) $\delta_{ij}\delta_{jk}$; e) $\delta_{ij}A_{ik}$.
20. Solve the problem. For the Lewy-Civita strainer ε_{ijk} directly writing on the indices show that: a) $\varepsilon_{ijk}\varepsilon_{kij} = 6$; b) $\varepsilon_{ijk}a_ja_k = 0$. $\varepsilon_{123} = \varepsilon_{231} = \varepsilon_{312} = 1$,
 $\varepsilon_{321} = \varepsilon_{132} = \varepsilon_{213} = -1$, rest = 0.
21. Solve the problem. In the axisymmetric flow in the direction of the axis x_3 speed is a function x_3 and r , where $r^2 = x_1^2 + x_2^2$. Find what kind of indissolubility equation takes when the velocity vector is represented in the form $\vec{v} = q\vec{e}_r + v_3\vec{e}_3$, where $\vec{e}_r$ – single vector of radial direction.
22. Solve the problem. For tensors $\mathbf{D} = 3\mathbf{ii} + 2\mathbf{jj} - \mathbf{jk} + 5\mathbf{kk}$ and $\mathbf{F} = 4\mathbf{ik} + 6\mathbf{jj} - 3\mathbf{kj} + \mathbf{kk}$ calculate double scalar product $\mathbf{D}:\mathbf{F}$.
23. Solve the problem. Show that any 2nd rank tensor given as the sum N diad can be reduced to the sum of three members if you use basic vectors $\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3$ as: a) the first multipliers, b) the second multipliers in the tiaras.
24. Solve the problem. In the orthogonal Cartesian coordinate system, determine: a) a single vector, parallel to the vector $\mathbf{v} = 2\mathbf{i} + 3\mathbf{j} - 6\mathbf{k}$ (or $\vec{v} = 2\vec{i} + 3\vec{j} - 6\vec{k}$); b) single vector of a line connecting points $P(1;0;3)$ and $Q(0;2;1)$.
25. Solve the problem. Write down the indissolubility equations in The Euler variables in an arbitrary curvilinear coordinate system using the physical components of the velocity vector. Get from it the equation of indissolubility: a) in the cylindrical coordinate system; b) in a spherical coordinate system.
26. Solve the problem. A stream is called flat-parallel if the speed v_x, v_y do not depend on cartesian coordinate z and $v_z = 0$. Given a flat parallel stream with a speed field $v_x = A \frac{x^2 - y^2}{r^4}$, $v_y = 2A \frac{xy}{r^4}$, $v_z = 0$, $A = \text{const}$, where x, y, z – Cartesian coordinates, $r = \sqrt{x^2 + y^2}$. Prove that the field is the speed field of the incompressible environment.
27. Solve the problem. Show mixed vector product $\mathbf{a} \cdot \mathbf{b} \times \mathbf{c} = 0$, if the vectors $\mathbf{a}, \mathbf{b}, \mathbf{c}$ they are linearly dependent. Check the linear dependence for the following three vectors:
 $\mathbf{u} = 3\mathbf{i} + \mathbf{j} - 2\mathbf{k}$;
 $\mathbf{v} = 4\mathbf{i} - \mathbf{j} - \mathbf{k}$;
 $\mathbf{w} = \mathbf{i} - 2\mathbf{j} + \mathbf{k}$.
28. Solve the problem. The adiabatic current (frictionless) of the ideal gas (which obeys Clapeyron's law) is a barotropic current and is described by the equation $p = C\rho^k$, where C and k – permanent, and $k = c_p / c_v$ – ratio of heat capacity at constant pressure and constant volume. Find the dependencies between temperature and density, as well as between temperature and pressure for this process.
29. Solve the problem. Determine the average normal stress $\sigma_{ii}/3$ in incompressible runoff (nonlinear) liquid for which $\tau_{ij} = \alpha D_{ij} + \beta D_{ik}D_{kj}$, and α, β – permanent, where $D_{ij} = \left(\frac{\partial v_j}{\partial x^i} + \frac{\partial v_i}{\partial x^j} \right) = v_{j,i} + v_{i,j}$ –

components of the deformation velocity strain tensor, c^{-1} ; V_i – components of the velocity vector, m/s.

30. Solve the problem. Get the equation of energy (thermal conductivity) in the cylindrical coordinate system.

List of issues and tasks submitted for modular control work

1. Analyze the related equations of linear thermoelasticity. Describe the initial and boundary conditions.
2. Analyze the concept of continuum. Describe the Lagrangian and Euler coordinates to describe the movement of bodies, a substance derivative of time.
3. Analyze quasi-static equations of thermo-binding plasticity. Describe the appropriate boundary conditions.
4. Analyze and compare the formulas for the vector product component of tensors based on the Levi-Civita tensor.
5. Analyze the general characteristics of physical phenomena and processes occurring in solids, liquids and gases. Describe the physical models of MC.
6. Describe the definition of MC and the axioms of the mechanics of continuum media.
7. Describe the vector bases in the initial and current configuration of bodies.
8. Prove the symmetry of tensors of stresses and deformations.
9. Describe the properties of the component of the metric strain gautor. Write down and analyze the relationships between covariant and contravariant components of the metric strain gaug.
10. Describe MC hypotheses and analyze their role in the development of mathematical models.
11. Describe the definition of the Levi-Civita strainer in orthogonal coordinate systems and its properties.
12. Analyze the main invariants of the tension strain strain. Describe the definition of maximum tangent stresses and orientation of the planes on which they operate.
13. Analyze and compare the main and mutual vector bases. Describe the properties of mixed product vectors.
14. Describe the concept of vector, coordinate systems. Analyze the representation of vectors in rectangular and oblique straight coordinates.
15. Describe the principle of cross section to determine internal forces.
16. Analyze the concept of covariant and contravariant components of the vector. Describe the actions on vectors.
17. Describe the concept of the vector of stress, average stress and tension at the point of the body. Get formulas for normal and tangent tensions on the plane.
18. Describe the concepts of dumb, free, covariant and contravariant indices and give examples of their application.
19. Analyze and compare the types of stress conditions. Describe Mora's circles.
20. Describe the definition of stresses on the inclined plane. Analyze the designation of stresses on coordinate planes and the rules of signs for them.
21. Describe the fundamental strain gauzes of coordinate systems: metric, coordinate conversion, Levi-Chivita.
22. Describe the definition of tensor. Analyze the representation of tensors through vectors of the main and mutual basis, vector support.
23. Analyze the patterns of changes in stresses when turning the coordinate system.
24. Describe the definition of centrosymmetric, flat and axisymmetric stress states and compare them.
25. Analyze and compare the unary actions over the tensor: transpose, scalar convolution, vector convolution, tensor trail.
26. Analyze and compare binary operations with tensors: the sum of tensors, scalar product, double scalar product, vector product, tensor product.

27. *Analyze the differential equations of statics and dynamics in cylindrical coordinates and compare them with Cartesian.*
28. *Analyze and compare the differentiation of tensors in a curvilinear coordinate system with Cartesian.*
29. *Describe the energy of elastic deformation. Analyze the concept of full potential energy of the body.*
30. *Analyze the representation of finite deformations through a linear deformation tensor and a linear rotation vector.*
31. *Describe the concept of the tensor gradient, give examples of its application in the physical equations of the MC.*
32. *Analyze the concept of the Hamilton operator, give examples of its application in MC equations.*
33. *Describe the temperature deformations.*
34. *Analyze geometric equations for finite deformations.*
35. *Analyze and compare the operators of divergence and rotor, give examples of their application in MC equations.*
36. *Describe curvilinear coordinates.*
37. *Describe the procedure for differentiating tensors in curvilinear coordinates.*
38. *Analyze Hook, Genky, Sinerini and compare them.*
39. *Analyze the laws of conservation of mass and the amount of movement in the MC.*
40. *Describe the properties of the symbols of Cristofel.*
41. *Analyze and compare the physical properties of elastically nonlinear, elastic-plastic solids.*
42. *Describe covariant derivatives from the tensor of the second rank given by the contravariant components.*
43. *Analyze the concept of dissipative function. Determine the equation of the relationship between thermodynamic potentials.*
44. *Describe the procedure for differentiating the strainbar given by covariant components.*
45. *Describe the physical equations of the state and the physical laws for solids.*

The working program of the educational component (syllabus):

Compiled by Professor, Doctor of Technical Sciences, Professor, Anton KARVATSKYI

Approved By the Department of Chemical, Polymer and Silicate Mechanical Engineering (Minutes No. 17 dated 04.06.2025)

Agreed By the Methodological Commission of the Faculty (Minutes No. 11 dated 06.27.2025)