Ministry of Education and Science of Ukraine

National Aerospace University
"Kharkiv Aviation Institute"

Department 202 «Theoretical Mechanics, Engineering and Robotic Systems»

APPROVED

Acting Head of Scientific
Methodical Committee

_____ H.B. Пуденко

«01» березня 2020

WORKING PROGRAM OF COMPULSORY ACADEMIC DISCIPLINE

"Engineering Mechanics (Theory of Mechanisms and Machines)"
(name of academic discipline)

Field of study: 13 «Mechanical Engineering»,
27 «Transport Services»
Specialities: 134 «Aviation and Aerospace Technologies»,
272 «Aviation Transport»

Educational programs: «Airplanes and helicopters»,
«Design and production of constructions from composite materials»,
«Production technologies of aircrafts»,
«Aircraft engines and power plants»,
«Satellites, engines and power plants»
«Maintenance service and repair of aircrafts and aircraft engines»

Full-time tuition
Level of higher education: bachelor's (first cycle)

Kharkiv 2020

Working program of academic discipline "Engineering Mechanics (Theory of Mechanisms and Machines)" is for students of program subject area 134 «Aviation and Aerospace Technologies»

Educational programs: «Airplanes and helicopters»,
«Design and production of constructions from composite materials»,
«Production technologies of aircrafts»,
«Aircraft engines and power plants»,
«Satellites, engines and power plants»
«Maintenance service and repair of aircrafts and aircraft engines»

June 23, 2020 - 10 p.

Developer: Anna Kuznetsova, Assosiate Professor of Department «Theoretical Mechanics, Engineering and Robotic Systems», PhD _____

Working program was approved at the meeting of Department 202 «Theoretical Mechanics, Engineering and Robotic Systems»
Minutes #10 – June 25, 2020

Head of Department, DSc, Assosiate Professor_____ O.O. Baranov

1. Description of the discipline

<table>
<tr><td rowspan="2">Characteristics</td><td rowspan="2">Branch of science, specialization, academic degree</td><td>Description of the discipline</td></tr>
<tr><td>full-time tuition</td></tr>
<tr><td>Credits – 3,5</td><td rowspan="3">Field of study:
13 «Mechanical Engineering»,
27 «Transport Services»</td><td>Compulsory</td></tr>
<tr><td>Module – 1</td><td rowspan="2">Academic year:</td></tr>
<tr><td>Thematic modules – 2</td></tr>
<tr><td rowspan="3"></td><td rowspan="3">Speciality:
134 «Aviation and Aerospace Technologies»,
272 «Aviation Transport»</td><td>2020/ 2021</td></tr>
<tr><td>Semester</td></tr>
<tr><td>4th</td></tr>
<tr><td rowspan="8">Total number of academic hours – 48/105
Number of weekly academic hours for full-time tuition:
auditorium – 3
independent work – 3,6</td><td rowspan="3"></td><td>Lectures, a.h.</td></tr>
<tr><td>32</td></tr>
<tr><td>Practices, seminars, a.h.</td></tr>
<tr><td rowspan="3">Level of higher education:
bachelor’s (first cycle)</td><td>16</td></tr>
<tr><td>Laboratory activities, a.h.</td></tr>
<tr><td>-</td></tr>
<tr><td rowspan="6"></td><td>Independent work, a.h.</td></tr>
<tr><td>57</td></tr>
<tr><td>Individual task, a.h.</td></tr>
<tr><td>-</td></tr>
<tr><td>Form of examination</td></tr>
<tr><td>examination</td></tr>
</table>

Note: ratio between classroom hours and student independent work hours for full-time education is equal: 48/57=0,84

2. The objective and outcomes of the course

The **objective** of the course is learning of methods of kinematic and dynamic analysis and synthesis of mechanisms to gain experience and practical skills in solving problems related to research mechanisms and components of aviation equipment.

The **task** of the course is to provide students with the knowledge and skills to design and research the mechanisms and machines and to explore the topics of kinematics and dynamics of machinery in respect to the synthesis of mechanisms in order to accomplish desired motions or tasks, and also the analysis of mechanisms in order to determine their dynamic behavior.

According to the requirements of the educational-professional program, students must achieve such **competencies**:

C02. Ability to communicate in a foreign language.

C06. Ability to generate new ideas (creativity).

C07. Ability to make informed decisions.

C08. Ability to learn and master modern knowledge.

C11. Ability to use theories of flight dynamics and control in the design of rocket and space technology.

C15. Ability to design and test elements of rocket and space technology, its equipment, systems and subsystems.

Program learning outcomes:

PLO02. Fluent in oral and written foreign language on professional matters.

PLO06. Have the skills of self-study and autonomous work to improve professional skills and solve problems in a new or unfamiliar environment.

PLO11. Have the skills to determine the loads on the structural elements of rocket and space technology at all stages of its life cycle.

PLO16. Apply modern methods of design, construction and production of elements and systems of rocket and space technology in professional activities.

PLO20. Understand and justify the design features and basic aspects of work processes in systems and elements of rocket and space technology.

Interdisciplinary connections: Physics, Theoretical Mechanics, Machine Elements, Higher Mathematics, Applied Mechanics, Construction Mechanics.

3. Course Content

Thematic Module №1. Analysis of mechanisms and machines.

1. Introduction. Structural analysis of mechanisms. Links and kinematic pairs. Kinematic chains. The structural formulas of spatial and planar mechanisms. Mobility of mechanisms.

2. Structural classification of mechanisms. Structural components of mechanism: basic mechanism, structural group. Order of structural analysis.

3. Kinematical analysis of mechanisms. Analytical method. Graph-analytical method. Kinematic analysis of lever mechanisms by analytical method of closed vectorial contours. Order of analysis of second class mechanisms with mobility $w = 1$. Kinematic analysis of lever mechanisms by graph-analytical method. Construction of velocity and acceleration diagrams for four-bar linkages of the second class.

4. Kinematic analysis of gear trains. Analytical method of gearings analysis. Gear ratio of simple gear trains. Linear and angular velocity diagrams of gearings.

5. Kinematic analysis of planetary and differential gear trains. Kinematic analysis by analytical method. Graphical method of epicyclic gearing analysis: construction of linear and angular velocity diagrams.

6. Dynamic analysis of mechanisms. Objectives and methods of dynamic analysis. Force analysis of mechanisms. The forces acting on the mechanism and their characteristics. Determination of reactions in kinematic pairs of four-bar linkages and balancing force (balancing moment) by Bruevich's method. Determination of mechanism balancing force by Zhukovsky's method.

7. Friction in kinematic pairs. Basic laws of sliding. Friction in radial and axial sliding bearings. Friction in helical sliding kinematic pairs. Rolling friction in radial and axial bearings.

8. Motion modes of mechanisms. Dynamic equations of speeding-up, steady-state motion and running-out. Mechanical efficiency. Efficiency of mechanisms connected in series and parallel.

Thematic Module №2. Synthesis of mechanisms and machines.

1. Dynamic model of the engine unit. Reduction of forces and moments of forces. Reduction of mass and moments of inertia. The equations of dynamic model motion. Irregularity factor of motion.

2. Synthesis of gearings. The main theorem of gearing and its consequence. Involute of a circle, its properties and equations. Involute meshing of cylindrical gears. Rack and pinion meshing.

3. Gear cutting. Generating process and form-copying method. Pitch circle, teeth module. Counter profile, standard basic rack tooth profile.

4. Types of gears, which formed by the rack. Addendum modification. Zero, positive and negative gears. Teeth undercut. Addendum modification limit for external gears dependent on the virtual number of teeth.

5. Determination of geometrical parameters of involute gears. Positive, negative and zero gearing. Base circle, working pitch circle, root circle, tip circle, tooth thickness on the pitch circle, tooth thickness on the arc of a circle of arbitrary radius, center distance, pressure angle

6. Qualitative indicators of involute gearing: transverse contact ratio, specific sliding, geometric coefficient of specific pressure. Selection of addendum modification coefficient. Blocking contours.

7. Synthesis of planetary and differential gear trains. Selection condition of planetary gearings schemes and number of gear teeth.

8. Synthesis of lever mechanisms. The conditions of crank existence in planar mechanisms. Synthesis of mechanisms by a variation factor of output link average speed, by pressure angle and by angle of force transmission.

4. Course arrangement

Names of Modules and Topics	Number of hours					
	full-time tuition					
	total	namely				
		lec	pr	lab	ind	i.w.
1	2	3	4	5	6	7
Module 1						
Thematic module 1. Analysis of mechanisms and machines						
TOPIC 1. Introduction. Structural analysis of mechanisms. Links and kinematic pairs. Kinematic chains. The structural formulas of spatial and planar mechanisms. Mobility of mechanisms.	8	2	2			4
TOPIC 2. Structural classification of mechanisms. Structural components of mechanism: basic mechanism, structural group. Order of structural analysis.	8	2	2			4
TOPIC 3. Kinematical analysis of mechanisms. Analytical method. Graph-analytical method. Kinematic analysis of lever mechanisms by analytical and graph-analytical methods. Construction of velocity and acceleration diagrams for four-bar linkages of the second class.	8	2	2			4
TOPIC 4. Kinematic analysis of gear trains. Analytical method of gearings analysis. Gear ratio of simple gear trains. Linear and angular velocity diagrams of gearings.	8	2	2			4

TOPIC 5. Kinematic analysis of planetary and differential gear trains. Kinematic analysis by analytical method. Graphical method of epicyclic gearing analysis: construction of linear and angular velocity diagrams.	8	2	2			4
TOPIC 6. Dynamic analysis of mechanisms. Objectives and methods of dynamic analysis. Force analysis of mechanisms. The forces acting on the mechanism and their characteristics. Determination of balancing force (balancing moment) by Bruevich's method and Zhukovsky's methods.	6	2				4
TOPIC 7. Friction in kinematic pairs. Basic laws of sliding. Friction in radial and axial sliding bearings. Friction in helical sliding kinematic pairs. Rolling friction in radial and axial bearings.	6	2				4
TOPIC 8. Motion modes of mechanisms. Dynamic equations of speeding-up, steady-state motion and running-out. Mechanical efficiency. Efficiency of mechanisms connected in series and parallel.	6	2				4
Totally for thematic module 1	**58**	**16**	**10**			**32**
Thematic module №2. Synthesis of mechanisms and machines						
TOPIC 1. Dynamic model of the engine unit. Reduction of forces and moments of forces. Reduction of mass and moments of inertia. The equations of dynamic model motion. Irregularity factor of motion.	8	2	2			4
TOPIC 2. Synthesis of gearings. The main theorem of gearing and its consequence. Involute of a circle, its properties and equations. Involute meshing of cylindrical gears. Rack and pinion meshing.	6	2				4
TOPIC 3. Gear cutting. Generating process and form-copying method. Pitch circle, teeth module. Counter profile, standard basic rack tooth profile.	6	2				4
TOPIC 4. Types of gears, which formed by the rack. Addendum modification. Zero, positive and negative gears. Teeth undercut. Addendum modification limit for external gears dependent on the virtual number of teeth.	6	2				4
TOPIC 5. Determination of geometrical parameters of involute gears. Positive, negative and zero gearing. Base circle, working pitch circle, root circle, tip circle.	7	2	2			3

TOPIC 6. Qualitative indicators of involute gearing. Selection of addendum modification coefficient. Limiting contours	4	2				2
TOPIC 7. Synthesis of planetary and differential gear trains. Selection condition of planetary gearings schemes and number of gear teeth.	6	2	2			2
TOPIC 8. Synthesis of lever mechanisms. The conditions of crank existence in planar mechanisms.	4	2				2
Totally for thematic module 2	**47**	**16**	**6**			**25**
Totally for term	**105**	**32**	**16**			**57**

5. Practices

№	Name	Hours
1	Mobility of mechanisms. Structural classification of mechanisms.	2
2	Structural analysis of mechanisms. Kinematic analysis of lever mechanisms.	2
3	Kinematic analysis of slotted link mechanisms	2
4	Kinematic analysis of six-bar linkage by means of graph-analytical method	2
5	Kinematic analysis of gear trains. Gear ratio of simple gear trains	2
6	Kinematic analysis of planetary and differential gear trains	2
7	Kinematic analysis of compound gear train	4
	Total	16

6. Independent work

№	Name	Hours
1	Structural analysis of mechanisms. Mobility of mechanisms	4
2	Structural components of mechanism: basic mechanism, structural group	4
3	Kinematic analysis of lever mechanisms.	4
4	Kinematic analysis of gear trains. Gear ratio of simple gear trains	4
5	Kinematic analysis of planetary and differential gear trains	4
6	Dynamic analysis of mechanisms	4
7	Friction in kinematic pairs	4
8	Motion modes of mechanisms	4
9	Reduction of forces and masses.	4
10	Synthesis of gearings. The main theorem of gearing and its consequence.	4
11	Gear cutting. Generating process and form-copying method.	4
12	Types of gears, which formed by the rack. Addendum modification.	4
13	Determination of geometrical parameters of involute gears.	3
14	Qualitative indicators of involute gearing.	2
15	Synthesis of planetary and differential gear trains	2
16	Synthesis of lever mechanisms.	2
	Total	57

7. Teaching methods

Lectures, practices; individual consultations; student self-study with the help of tutorials published by chair; Olympiad.

8. Grading

The course is divided into two modules:

1. Analysis of mechanisms and machines
2. Synthesis of mechanisms and machines

Module 1 is passed during 8-th week (one attempt), module 2 is passed during 16-th week (one attempt).

Before passing modules, student must defend practice tasks of this module.

Deadlines for submission and defense of practices tasks are 8^{th} week and 16^{th}.

After deadline time students do not obtain points for practice tasks.

Examination.

9. Points distribution between topics

9.1 Points in module system

Module component	Points	Number of tasks	Total points
Thematic module 1			
Module passing	0 ÷ 30	1	0 ÷ 30
Performance and defense of practice "Kinematic analysis of six-bar linkage by means of graph-analytical method"	0 ÷ 20	1	0 ÷ 20
Thematic module 2			
Module passing	0 ÷ 30	1	0 ÷ 30
Performance and defense of practice "Kinematic analysis of compound gear train"	0 ÷ 15	1	0 ÷ 15
Independent solution of extra problem	0 ÷ 5	1	0 ÷ 5
Total			0 ÷ 100
Examination	100		

The examination is carried out in case of refusal of the student from points of current testing and if he has the admission to exam. Maximum mark of the exam is 100 points.

The question paper of examination consists of :

1) Theoretical question – 60 points;
2) Problem 1- 20 points;
3) Problem 2 – 20 points.

9.2 Qualitative evaluation criteria

The amount of knowledge required to obtain a positive assessment.

Student should know:

- classification and scope of mechanisms use;
- general methods of design and research of mechanisms;

- mathematical modeling of mechanical systems dynamics;
- methods of kinematic synthesis and analysis of mechanisms including aircraft engines units;
- methods of dynamic analysis and synthesis of mechanisms

The required amount of skills to receive a positive assessment.

The student must be able to:

- formulate a mathematical model of studied mechanical system (motion, balance);
- use modern methods of kinematic and dynamic analysis for mechanisms research;
- carry out an analysis of mathematical calculations;
- make structural analysis of mechanisms;
- project kinematic diagrams of mechanisms according to structural, kinematic and dynamic conditions;
- use mathematical methods of gear mechanisms research;
- choose rational schemes of planetary gears for aircraft engineering.

9.3 Criteria for assessing student work during the semester

Satisfactory (60-74). Have a sufficient minimum of knowledge and skills. Perform and protect all tasks included in the calculation work. Know the equilibrium conditions for different types of force systems. Know what the kinematic and dynamic equations of translational, rotational and axis rotation and plane-parallel motion. Be able to do structural analysis of mechanisms, synthesis of planetary, differential gear trains and lever mechanisms and determine mobility of mechanisms.

Good (75-89). Perform and protect in the time specified in the work program all tasks that are part of the calculation work. Know the equilibrium conditions for different types of force systems. Know what the kinematic and dynamic equations of translational, rotational and axis rotation and plane-parallel motion. Be able to do kinematic analysis of lever mechanisms by means of analytical and graph-analytical methods. Show the ability to analyze the results of solving practical problems. Know and be able to put into practice methods of describing the motion (or equilibrium) of a mechanical system in generalized coordinates. Be able to create dynamic model of mechanism. Be able to determine geometrical parameters of involute gears.

Excellent (90 - 100). It is unmistakable to execute and protect with maximum marks and within the time specified by the teacher, all tasks that are part of the calculation work. Full knowledge of basic and additional material. Navigate your textbooks and guides. Be able to deduce and explain any formula and prove any theorem provided by the program. Show the ability to analyze the results of solving practical problems

National scale and ECTS grade

<table>
<tr><td rowspan="2">Total score</td><td rowspan="2">ECTS scale</td><td colspan="2">Mark on national scale</td></tr>
<tr><td>exam, course project</td><td>credit</td></tr>
<tr><td>90 – 100</td><td>A</td><td>Excellent</td><td rowspan="5">Passed</td></tr>
<tr><td>83 – 89</td><td>B</td><td rowspan="2">Good</td></tr>
<tr><td>75 – 82</td><td>C</td></tr>
<tr><td>68 -74</td><td>D</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>60 – 67</td><td>E</td></tr>
<tr><td>1 – 59</td><td>FX</td><td>Fail (exam repeating is possible)</td><td>Failed (credit repeating is possible)</td></tr>
</table>

Student which passed all modules, can take total rating score and not pass final test. If student is not agree with total rating score, he can improve it passing final test.

Total rating score is transformed into ECTS and National score using recommended grade scales

10. Procedural guidelines

1. Theoretical mechanics. Kinematics: Tutorial for self-education / V. N. Pavlenko, I. V. Bunyaeva, S. S. Vorozhko et al. – Kharkov: National Aerospace University named after N. Ye. Zhukovskiy «Kharkov Aviation Institute», 2012. – 96 p.
2. Theoretical mechanics. Dynamics: Textbook / V. N. Pavlenko, I. V. Bunyaeva, S. S. Ternovskaya et al. – Kharkov: National Aerospace University named after N. Ye. Zhukovskiy «Kharkov Aviation Institute», 2013. – 184 p.

Lectures are supported by PowerPoint presentation. Handout referring to the actual topics is distributed during lectures and practices.

11. Recommended literature for the course

Basic

3. John J. Uicker, Jr., Gordon R. Pennock, and Joseph E. Shigley, Theory of Machines and Mechanisms, Fifth Edition – McGraw-Hill series in mechanical engineering, 2017.
4. R.S. Khurmi, J.K. Gupta, Theory of Machine - Eurasia Publishing House, 2015.
5. Thomas Bevan, The Theory of Machines – CBS Publishers and Distributors, 2016.
6. The Theory of Machines by Robert Ferrier McKay – Edward Arnold, London, 2017.
7. C.H. Jensen, J.D. Helsel, Engineering Drawing And Design. - McGraw-Hill Science, 7th Edition, 2015.
8. J. A. Collins, H. R. Busby, G. H. Staab, Mechanical Design of Machine Elements and Machines. - Wiley, 2nd Edition, 2018.

Auxiliary

1. F.P. Beer and E.R. Johnston, Vector Mechanics for Engineers – Statics. Dynamics, McGraw Hill Book Company, 2003.
2. J.L. Meriam and L.G. Kraige, Engineering Mechanics – Statics. Dynamics, John Wiley & Sons, 2002.

12. Information sources

http://elartu.tntu.edu.ua/bitstream/lib/26905/1/nove_TMM_angl_metod_2018-converted%20%281%29.pdf