MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
National Aerospace University
"Kharkov Aviation Institute"

Aircraft Engine Theory department (№ 201)

APPROVED
Head of project team

_____ *Oleksandr Bilohub*
(signature) (first and last name)

«_____» _____ 2020

SYLLABUS OF AN ACADEMIC DISCIPLINE

THEORY AND COMPUTATION OF IMPELLER MACHINES

(name of academic discipline)

Field of education *13 «Mechanical Engineering»*
(code and name of a field of education)

Field of study *134 «Aerospace Engineering»*
(code and name of field of study)

Educational program *Aircraft engines and power plants*
(code and name of educational program)

Form of training *Full-time studies*

Level of higher education *First (bachelor)*

Kharkiv 2020

Working program *Theory and Computation of Impeller Machines*
(name of academic discipline)
for students of a field of study *134 «Aviation and Spacecraft Technologies»*
educational program *Aircraft engines and power plants*

« *20* » August 2020 – 10 p.

Person, who developed the syllabus *Kseniia Fesenko Associate Professor, PhD*
(author, job, academic degree and rank) (signature)

Working program was approved at the meeting of the department
Aircraft Engine Theory
(department)

Minutes № 1 dated « 31 » August 2020

Head of department *Dr. Sc., Professor* *Ludmyla Boyko*
(academic degree and rank) (signature) (first and last name)

The program is approved at the graduating department
Aircraft Engine Design
(department)

Minutes № 1 dated « 28 » August 2020

Head of department *Dr. Sc., Professor* *Sergiy Yepifanov*
(academic degree and rank) (signature) (first and last name)

1. Description of the discipline

<table>
<tr><td colspan="2">Characteristics</td><td>Branch of science, specialization, academic degree</td><td colspan="2">Description of the discipline (full-time tuition)</td></tr>
<tr><td colspan="2">Credits – 4,5 + 5</td><td>Field of education:
13 «Mechanical Engineering»
(cipher and name)</td><td colspan="2">Variable</td></tr>
<tr><td colspan="2">Modules – 4</td><td rowspan="5">Field of study:

134
Aerospace Engineering
(cipher and name)</td><td colspan="2">Academic year:</td></tr>
<tr><td colspan="2">Semantic modules – 4</td><td colspan="2">2020 / 2021</td></tr>
<tr><td colspan="2">Individual tasks:
Calculation-graphic work (5 semester) "Calculation of the Flow Parameters along the GTE Air-Gas Channel"
Calculation work (6 semester) "Kinematics of the Flow in the Axial Compressor Stage"
Course work (6 semester) "Gas-Dynamic Design of Impeller Machines of a Gas-Turbine Engine"</td><td colspan="2">Semester</td></tr>
<tr><td colspan="2">Total number of academic hours – 285</td><td>5</td><td>6</td></tr>
<tr><td colspan="2"></td><td colspan="2">Lectures</td></tr>
<tr><td colspan="2">Number of academic hours for full-time studies per week:</td><td rowspan="9">Educational program:
Aircraft Engines and Power Plants

Higher education:
First (Bachelor)</td><td>48 a.h.</td><td>32 a.h.</td></tr>
<tr><td colspan="2">Semester 5</td><td colspan="2">Practices</td></tr>
<tr><td>auditorium – 4</td><td>independent work – 4,4</td><td>-</td><td>24 a.h.</td></tr>
<tr><td colspan="2">Semester 6</td><td colspan="2">Laboratory activities</td></tr>
<tr><td>auditorium – 4,5</td><td>independent work – 4,9</td><td>16 a.h.</td><td>16 a.h.</td></tr>
<tr><td colspan="2"></td><td colspan="2">Independent work</td></tr>
<tr><td colspan="2"></td><td>71 a.h.</td><td>78 a.h.</td></tr>
<tr><td colspan="2"></td><td colspan="2">Form of examination</td></tr>
<tr><td colspan="2"></td><td>exam</td><td>exam, differential credit</td></tr>
</table>

Note

The ratio of auditorium hours to independent work is:
for full-time education in 5-th semester – 64 / 71.
for full-time education in 6-th semester – 72 / 78.

2. Goals and purposes of discipline

Goal: mastering by students of the basic provisions of the theory of impeller machines of gas turbine engines and application at designing of stages and multistage compressors and turbines and development of systems of their regulation.

Task: study of the principles of operation of impeller machines of different types, basic equations and ratios that reflect gas-thermodynamic processes in the flow purifiers of impeller machines, airfoil cascades, understanding the features of their operation in different modes, the ability to choose their parameters at the design stage base of calculations sketch projects of impeller machines of gas turbine engines.

As a result of studying the discipline the student should

know:

– classification, schemes and principle of operation of impeller machines, basic definitions and requirements for them;

– basic thermos-gas-dynamic equations and relations that determine the processes in the impeller machines;

– requirements for the choice of parameters when performing calculations of impeller machines;

– methods of profiling of axial compressor blades and turbines by radius;

– theoretical and actual characteristics of the stages of the impeller machines;

– means of depicting the characteristics of the impeller machines in the similarity parameters;

– unstable modes of operation of compressors;

– characteristics of unregulated multistage compressors and turbines;

– regulation of compressors, means and their influence;

– the influence of operating conditions on the operating modes of compressors;

– features of operation of cooled stages of turbines and a choice of their parameters at designing;

– basics of mathematical modeling of processes in impeller machines.

be able:

– to apply the basic thermos-gas-dynamic relations for the calculation and analysis of the operation of impeller machines;

– evaluate the efficiency of the impeller machine and its elements depending on the processes that they have;

– to solve problems of determining the parameters of energy-isolated processes and processes with the exchange of thermal and mechanical energy;

– to draw graphs of processes in the impeller machine and its elements in the entropy diagram;

– to draw and analyze velocity diagrams at different values of kinematic parameters and reactivity coefficients;

– to determine the most favorable laws of twisting of profiling of blades on height;

– to calculate and draw the characteristics of impeller machines in the parameters of similarity;

– to determine unstable modes of impeller machines;

– to offer a means of regulating a multistage compressor in accordance with the mode of its operation;

– to determine the influence of operating conditions on the characteristics of multistage compressors;

– to choose the parameters of the impeller machines in their design in accordance with the design mode of the engine;

– to perform calculations of geometric parameters of multistage compressors and turbines agreed with the design parameters of the engine;

– to choose the amount and parameters of cooling air in the cooled stages of the turbines, determine their geometric parameters.

have an idea about:

– application of the basic equations of gas dynamics and thermodynamics for the calculation of impeller machines;

– the use of the entropy diagram to analyze the efficiency of processes in the impeller machine;

– drawing of velocity diagrams and their use for the analysis of the selected operating modes and geometrical parameters of airfoil cascades;

– selection of parameters of single- and multistage compressors and turbines during their design;

– calculations and obtaining geometric parameters of flow paths of compressors and turbines of aircraft engines;

– calculations of geometric parameters of the impeller machine stages at different radii along the height of the blade.

Interdisciplinary links: studying the discipline requires knowledge of the disciplines "Higher Mathematics", "Physics", "Technical Thermodynamics", "Gas Dynamics". It further provides training in the following disciplines "Theory of Air-Jet Engines", "Design and Dynamics of Aircraft Engines and Auxiliary Units", "Design of Aircraft Power Plants and Units", execution of course projects and bachelor thesis.

3. Course content

Module 1 General questions of the theory of impeller machines

Topic 1. Subject and tasks of the course. Its place in educational plan. Bibliography. Classification of impeller machines and areas of application of impeller machines, requirements for them. A brief history of impeller machines development. Constructive schemes of impeller machines. The contribution of university scientists to the development of impeller machines theory. Promising parameters of modern turbomachines. New approaches to design.

Topic 2. Equation of continuity, the law of conservation of energy, quantity and moment of momentum, state, isentropic and polytropic process. Generalized Bernoulli equation. Entropy diagram and its properties. Study of processes in the gas flow. Energy-isolated processes, their drawing in the entropy diagram. Processes with supply and removal of mechanical and thermal energy, their drawing in the entropy diagram. Equations of heat transfer and Bernoulli for flow in relative motion.

Module 2 Compressor stage theory

Topic 3. The axial compressor stage, its principle of operation, the purpose of the main elements, the process in the axial compressor stage, the main parameters, their effect on pressure ratio and efficiency. Velocity diagrams. Drawing of the process in the entropy diagram. Airfoil cascades, their geometric parameters, connection of flow kinematics with cascade geometric parameters. Forces acting on the blades of the turbomachine. Zhukovsky theorem of the profile lifting force in the cascade. Coefficients of lifting and resistance, cascade quality. Characteristics of compressor airfoil cascades, taking into account the compressibility and viscosity of the flow when calculating the cascades. Influence of inlet guide vanes. Features of gas-thermodynamic processes in sub-, trans- and supersonic stages of the compressor. Spatial flow in the stages of turbomachines. Conditions of joint work of stage elements located on different radii, laws of blades profiling on radius. Types of energy losses in the stage of the axial compressor.

Topic 4. Principle of operation, purpose of the main elements, basic geometric and thermogas-dynamic parameters of the centrifugal compressor stage. Velocity diagrams. Regularities of change of parameters along a flowing path. The blade angle at the impeller outlet and its influence on pressure ratio and efficiency.

Module 3 Axial turbine stage theory and characteristics of impeller machines

Topic 5. Gas turbine stage, principle of operation, purpose of basic elements, gas-thermodynamic processes, basic parameters of the stage, their influence on its work, efficiency of the turbine stage, velocity diagrams, active and reactive stages. Features of the flow of the turbine stage by subsonic flow. Types of mechanical energy losses in the turbine stage. Cooling of gas turbines.

Topic 6. The transition from theoretical to actual characteristics of the stages of the impeller machines, the characteristics of the axial compressor stage, unstable modes of operation of the stage, the reasons that cause them, the coefficient of stability of the compressor stage, the effect of rotational speed. Features of the manifestation of rotational failure in stages with different hub diameter. Similarity parameters. Representation of characteristics of turbomachines in similarity parameters. Characteristics of the axial gas turbine stage.

Module 4 Multistage axial compressors and gas turbines, their regulation

Topic 7. Multistage axial compressor, basic parameters, connection with compressor stage parameters. Selection of stage parameters at designing on the design mode. Terms of coordination of joint work of stages in the multistage compressor. Characteristics of unregulated multistage compressor, the nature of the mismatch of stages when changing the flow rate and rotational speed. Unstable operating modes. Range of operating modes, influence of pressure ratio. Means of compressors regulating and their application in different modes.

Topic 8. Multistage axial turbines. Basic parameters, connection with stage parameters. Selection of stages parameters at designing on the design mode. Features of design of cooled turbine stages. Performance evaluations. Off-design operating modes, characteristics of a multistage turbine, features of joint operation of stages. Drawing of characteristics. Means of regulation by turning the nozzle vanes.

4. Course arrangement

Names of Modules and Topics	Number of hours				
	full-time tuition				
	total	namely			
		lec	pr	lab	i.w.
1	2	3	4	5	6
Semester 5					
Module 1 General questions of the theory of impeller machines Semantic module 1					
Topic 1. General questions of the theory of impeller machines	35	8	6	2	19
Topic 2. Main equations in the theory of impeller machines	51	12	-	2	37
Modular testing	2	-	-	-	2
Totally for module 1	**88**	**20**	**6**	**4**	**58**
Module 2 Compressor stage theory Semantic module 2					
Topic 3. Axial compressor stage theory	67	22	6	6	33
Topic 4. Centrifugal compressor stage theory	22	6	-	6	10
Modular testing	2	-	-	-	2
Totally for module 2	**91**	**28**	**6**	**12**	**45**
Module 3 Axial turbine stage theory and characteristics of impeller machines Semantic module 3					
Topic 5. Axial turbine stage theory	18	8	-	4	6
Topic 6. Characteristics of impeller machines	39	10	6	8	15
Modular testing	2	-	-	-	2
Totally for module 3	**59**	**18**	**6**	**12**	**23**
Module 4 Multistage axial compressors and gas turbines, their regulation Semantic module 4					
Topic 7. Multistage axial compressors	35	10	6	4	15
Topic 8. Multistage axial turbines	10	4	-	-	6
Modular testing	2	-	-	-	2
Totally for module 4	**47**	**14**	**6**	**4**	**23**
Totally for course	**285**	**80**	**24**	**32**	**149**

5. Laboratory works

№	Name	Hours
	Semester 5	
1.	Acquaintance with flowing paths of aviation gas-turbine engines and their elements	4
2.	Axial-flow compressor stage	2
3.	Velocity diagrams for an axial-flow compressor stage	4
4.	Centrifugal-flow compressor	2
5.	Determination of the coefficient of a finite number of blades influence	4
	Semester 6	
6.	Axial-flow turbine	4
7.	Centrifugal-flow compressor performance	4
8.	Determination of gas-dynamic stability margins of a turbo-jet engine compressor	4
9.	Axial-flow gas turbine performance	4
	Total	**32**

6. Practical works

№	Name	Hours
	Semester 6	
1.	Selection and justification of the gas-turbine engine parameters. Thermo-gas-dynamic calculation of the gas-turbine engine.	4
2.	Matching calculation of compressors and turbines parameters, definition of geometrical sizes of these units.	4
3.	Gas-dynamic design calculation of the compressor on the middle radius	6
4.	Axial compressor blade profiling	6
5.	Formation of the flowing path of the gas-turbine engine in the form of a diagram	4
	Total	**24**

7. Independent work

№	Name	Hours
	Semester 5	
1.	Bibliography survey (Topic 1).	10
2.	Analysis of the application of the equations of gas dynamics and thermodynamics in the calculations of the gas-turbine engine components (Topic 2).	10
3.	The axial compressor stage. Types of airfoil cascades. Zhukovsky theorem with taking into account the manifestations of flow compressibility (Topic 3).	10
4.	Influence of the shape of the centrifugal blade of the compressor at the inlet and outlet on its characteristics (Topic 4).	10
5.	Execution of the calculation-graphic work on the topic "Calculation of the Flow Parameters along the GTE Air-Gas Channel"	27
6.	Modular testing	4
	Semester 6	
7.	The axial turbine stage. Features of drawing of velocity diagrams in the compressor and turbine stages (Topic 5).	6
8.	Characteristics of compressor and turbine stages (Topic 6).	6

9.	Influence of regulation of the multistage axial compressor on its characteristics (Topic 7).	6
10.	Features of the characteristics of the multistage turbine during the locking of its stages (Topic 8).	6
11.	Execution of the calculation work on the topic: "Kinematics of the Flow in the Axial Compressor Stage"	14
12.	Execution of the course work on the topic "Gas-Dynamic Design of Impeller Machines of a Gas-Turbine Engine"	36
13.	Modular testing	4
	Total	**149**

8. Individual tasks

№	Name	Hours
	Semester 5	
1.	Calculation-graphic work on the topic "Calculation of the Flow Parameters along the GTE Air-Gas Channel"	27
	Semester 6	
2.	Calculation work on the topic: "Kinematics of the Flow in the Axial Compressor Stage"	14
3.	Course work on the topic "Gas-Dynamic Design of Impeller Machines of a Gas-Turbine Engine"	36
	Total	**77**

9. Learning methods

Basic forms of learning: lectures; laboratory works; practical works; individual tasks; independent work; individual consultations.

10. Control methods

Conducting current control, written modular control, final control in the form of an exam and differential test (based on the results of the defense of the course work).

11. Evaluation criteria and distribution of the points that the students get

Semester 5

№	Components of educational work	Points for one lesson (task)	Number of lessons (tasks)	Total number of points
	Module 1			
1	Work at lectures		10	0 – 3
2	Execution of laboratory works	0 – 2	2	0 – 4
3	Defense of laboratory works	0 – 3	2	0 – 6
4	Modular testing	0 – 29	1	0 – 29
Totally for module 1				**0 – 42**
	Module 2			
1	Work at lectures		14	0 – 4
2	Execution of laboratory works	0 – 2	3	0 – 6
3	Defense of laboratory works	0 – 3	3	0 – 9
4	Execution of the calculation-graphic work	0 – 5	1	0 – 5
5	Defense of the calculation-graphic work	0 – 5	1	0 – 5
6	Modular testing	0 – 29	1	0 – 29
Totally for module 2				**0 – 58**
Totally for semester 5 (exam)				**0 – 100**

Semester 6

№	Components of educational work	Points for one lesson (task)	Number of lessons (tasks)	Total number of points
Module 3				
1	Work at lectures		9	0 – 4
2	Execution of laboratory works	0 – 2	2	0 – 4
3	Defense of laboratory works	0 – 3	2	0 – 6
4	Modular testing	0 – 29	1	0 – 29
Totally for module 3				**0 – 43**
Module 4				
1	Work at lectures		7	0 – 3
2	Execution of laboratory works	0 – 2	2	0 – 4
3	Defense of laboratory works	0 – 3	2	0 – 6
4	Execution of the calculation-graphic work	0 – 7	1	0 – 7
5	Defense of the calculation-graphic work	0 – 8	1	0 – 8
6	Modular testing	0 – 29	1	0 – 29
Totally for module 4				**0 – 57**
Totally for semester 6 (exam)				**0 – 100**

Semester 6

№	Components of educational work	Points for one lesson (task)	Number of lessons (tasks)	Total number of points
1	Work on practical classes		12	0 – 5
2	Execution of the course work	0 – 55	1	0 – 55
3	Defense of the course work	0 – 40	1	0 – 40
Totally for semester 6 (differential test)				**0 – 100**

Accepted evaluation scale

The sum of points for all types of educational activities	Assessment for the exam, course project (work), test, practice
90-100	excellent
75-89	good
60-74	satisfactory
01-59	unsatisfactory with the possibility of re-taking the exam

Semester testing (examination) is held in case the student gives up points of modular testing and is permitted to the examination. The permission is given if the student has finished and passed all laboratory works and also successfully defended the individual tasks.

Maximum total score of the examination is 100 points.

The examination card is composed of two theoretical questions and one practical task. The theoretical questions are distributed as follows:

–the first question from module 1 (module 3) (30 points);

–the second question is from module 2 (module 4) (30 points);

–the third question is the practical task (40 points).

12. Recommended literature for the course

1. Nezym, V. Yu. Familiarization with Flow Passages and Turbomachines of Aviation Gas Turbine Engines: laboratory work manual in English / V. Yu. Nezym, Yu. G. Nikolaenko. – Kh.: Nat. Aerospace Univ. “Kh. Aviation Inst.”, 2014. –16 p.

2. Anyutin, A. N. Theory of Turbomachinery: Laboratory Course Manual/ A. N. Anyutin, V. Yu. Nezym, G. V. Pavlenko, I. I. Redin – Kh.: Nat. Aerospace Univ. “Kh. Aviation Inst.”, 2016. – 48 p.

3. Cohen, H. Gas Turbine Theory/ H. Cohen, G.F.C. Rogers, H.I.H. Sarawanamutto – Longman Group, 1996. – 442 p.

4. Lakshminarayana, B. Fluid Dynamics and Heat Transfer of Turbomachinery/ B. Lakshminarayana – Wiley-Interscience, 1995. – 809 p.

5. Turton, R. K. Principles of Turbomachinery/ R. K. Turton. – Chapmann&Hall, 1995. – 265 p.