Національний технічний університет України
«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»

Department of automation of electric and mechatronic complexes

Hydrogen transportation technologies

Work program of the discipline (Syllabus)

Requisites of the academic discipline

Degree of higher education	***Second (Master)***
Field of study	*14 Electric enginreering*
Specialty	*141 Electric Power Engineering, Electrotechnics and Electromechanics*
Study programme **Certificate progremme**	*Engineering of Intellectual Electrotechnical and Mechatronic Complexes* *Engineering and automation of hydrogen energy systems and technologies*
Status of the discipline	*Selective*
Form of study	*Full-time/part-time/distance learning*
Year of study, semester	*1st year of study/ spring semester*
Volume of the discipline	*4 credits 120 hours (36 lectures, 18 practical, 66 SSW)*
Semester control/ control activities	*Credit, MCW*
Timetable	*http://rozklad.kpi.ua/*
Language of study	*English*
Information about the course leader / teachers	Lecturer: associate professor, PhD, senior researcher, Anna V. Yakovlieva, *tel. +38 063 630 89 59, e-mail: a.v.iakovlieva@lll.kpi.ua*[1] Practical lessons: associate professor, PhD, senior researcher, Anna V. Yakovlieva, *тел. +38 063 630 89 59, e-mail: a.v.iakovlieva@lll.kpi.ua*
Placement of the course	Available on the Google Classroom platform. The access code is provided by the teacher at the first lesson.

Program of the discipline

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

The transition to alternative energy and power sources has become an integral part of the development of modern society in the context of sustainable development. One of the newest challenges of the modern energy sector is a systematic and safe transition to the use of hydrogen as an energy source. Hydrogen energy at transport facilities is a way to reduce energy imports, ensure the state's energy independence and minimize the negative impact of transport and industry on the environment.

The *purpose* of studying the discipline is to form the student's theoretical knowledge and practical skills in the use of hydrogen for powering vehicles. The study of the material of this discipline is focused

[1] The teacher's e-mail or other contacts for feedback, it is possible to specify office hours or hours for communication in case of contact numbers. For a syllabus of a discipline taught by many teachers (for example, history, philosophy, etc.), you can specify a page on the website where contact information for the teachers for the relevant groups, faculties, institutes is provided.

on in-depth learning of the basics of engineering activities in the field of production and use of hydrogen in transport.

The *subject* of the discipline is the systems of production and use of hydrogen in vehicles.

Program learning *outcomes*:

Ability to solve complex specialized problems and practical problems related to the production, accumulation and storage of hydrogen for energy and transport.

To develop and implement systems for the accumulation, storage, transportation and use of hydrogen of various types and capacities in traditional energy for the accumulation of peak electricity. Build fuel cell transmission components using appropriate safety devices for hydrogen transportation technologies.

2. Prerequisites and post-requisites of the discipline (place in the structural and logical scheme of study in the relevant educational program)

The discipline "Hydrogen Transport Technologies" is taught on the basis of the knowledge and skills acquired by students during the study of credit modules in such disciplines as Transport Systems of Electromechanical Complexes, Hydraulics and Hydropneumatic Drive, Electric Machines and Technical Mechanics.

The knowledge and skills acquired in the course of studying the discipline "Hydrogen Transport Technologies" are necessary for specialists in this specialty who solve engineering problems in the field of electricity and electrical engineering and in the study of the disciplines "Infrastructure of hydrogen production and storage technologies for energy and transport", "Engineering and technical regulation in the field of hydrogen production and use", etc.

3. Content of the discipline

Section 1. Introduction to the course "Hydrogen transportation technologies":

Topic 1: General concepts of hydrogen production and use in the fuel and energy sector.

Topic 2. Classification of hydrogen by production methods and degree of environmental friendliness

Section 2: Use of hydrogen in vehicles

Topic 2.1. Use of hydrogen in internal combustion engines.

Topic 2.2: The use of fuel cells to power vehicles.

Topic 2.3: Use of hydrogen fuel in air transport

Section 3. Infrastructure for the use of hydrogen:

Topic 3.1. Hydrogen storage and transportation systems.

Topic 3.2. Safety of storage and use of hydrogen fuel4. Навчальні матеріали та ресурси

Basic literature:

1. Velu Subramani, Angelo Basile, T. Nejat Veziroğlu, Compendium of Hydrogen Energy, Woodhead Publishing, 2015, https://doi.org/10.1016/B978-1-78242-361-4.01002-5.

2. Tariq Muneer, Mohan Lal Kolhe, Aisling Doyle, Electric Vehicles: Prospects and Challenges, Elsevier, 2017, https://doi.org/10.1016/C2014-0-04033-6

3. A. Perner, J. Vetter, Editor(s): Bruno Scrosati, Jürgen Garche, Werner Tillmetz, Advances in Battery Technologies for Electric Vehicles, Woodhead Publishing, 2015 https://doi.org/10.1016/C2014-0-02665-2

4. G. Pollet, I. Staffell, J.L. Shang, V. Molkov, 22 - Fuel-cell (hydrogen) electric hybrid vehicles, Editor(s): Richard Folkson, Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance, Woodhead Publishing, 2014, Pages 685-735, https://doi.org/10.1533/9780857097422.3.685.

5. Kingshuk Dutta, Direct Methanol Fuel Cell Technology, Elsevier, 2020, https://doi.org/10.1016/C2018-0-04199-7

6. Nejc Klopčič, Ilena Grimmer, Franz Winkler, Markus Sartory, Alexander Trattner, A review on metal hydride materials for hydrogen storage, Journal of Energy Storage, Volume 72, Part B, 2023, 108456, https://doi.org/10.1016/j.est.2023.108456

Additional literature:

1. Paul Breeze, Piston Engine-Based Power Plants, Academic Press, 2018, https://doi.org/10.1016/C2016-0-03647-1

The literature, the bibliography of which is given with a reference, can be found on the Internet. Literature that does not contain references can be found in the library of Igor Sikorsky Kyiv Polytechnic Institute. Some sections of the basic literature [1]-[5] are required reading. The sections of the basic literature that are required for reading, as well as the relationship of these resources to specific topics of the discipline, are given below in the methodology for mastering the discipline. All other literary sources are optional and are recommended to be read

Educational content

5. Methods of mastering the discipline (educational component)

Active learning strategies are applied, which are determined by the following methods and technologies: problem-based learning methods (research method); personality-oriented technologies based on such forms and methods of teaching as case technology and project technology; visualization and information and communication technologies, including electronic presentations for lectures. The methodology of teaching the discipline combines visual teaching methods with explanation. Teaching is conducted in the form of lectures, laboratory and practical classes. The problem-solving method is used in the calculation work.

Lectures

No	Title of the lecture topic and a list of key issues (references to literature)
1	**Lecture 1:** Topic 1.1. Current state of hydrogen energy in Ukraine and the world. Prospects for development. Strengths and weaknesses of the development and implementation of hydrogen energy. **References: [3], [4].**
2	**Lecture 2:** Topic 1.1. Legal and regulatory framework in the field of hydrogen energy in the leading countries of the world and in Ukraine. **References: [2], [4].**
3	**Lecture 3:** Topic 1.1. General concepts of hydrogen and hydrogen fuel. Properties of hydrogen. Structure of hydrogen production and use in the world. **References: [1], [3], [4].**
4	**Lecture 4.** Topic 2.1. Methods of hydrogen production. Classification of hydrogen by production methods. Raw materials for hydrogen production. **References: [1], [2], [3].**
5	**Lecture 5-6.** Topic 2.1. Overview of technological processes of hydrogen production. Electrolysis of water. Steam conversion of methane. Gasification of coal. Conversion of biomass. Alternative methods of hydrogen production. **References: [1], [2], [3].**
6	**Lecture 7-8.** Topic 2.1. World experience in the production and use of internal combustion engines running on hydrogen. The use of hydrogen in internal combustion engines. Design of a hydrogen internal combustion engine. Principle of operation of hydrogen internal combustion engines. Performance indicators of internal combustion engines using hydrogen. **References: [1], [3], [4].**
7	**Lecture 9-10.** Topic 2.2. Fuel cells. World experience in the production and application of modern fuel cells Classification of fuel cells. Design and principle of operation. Advantages and disadvantages of modern fuel cells.

	References: [1], [2], [4].
8	**Lecture 11-12.** Topic 2.3: The use of hydrogen in aviation transport. Gas turbine engines using compressed and/or liquid hydrogen. Fuel cells in air transport. Use of hybrid power plants on board aircraft. **References: [1], [2], [5].**
8	**Lecture 13-14.** Topic 3.2. Infrastructure of hydrogen transportation technologies. Stationary and mobile hydrogen storage systems. Hydrogen transportation and supply systems. **References: [1], [3], [4].**
9	**Lecture 15-16.** Topic 3.2. Alternative methods of hydrogen accumulation and storage to meet the needs of the transport industry. Hydrogen storage systems in metal hydrides. Chemical storage of hydrogen. The use of nanomaterials for hydrogen storage. **References: [5], [6].**
10	**Lecture 17.** Topic 3.3: Safety of storage and use of hydrogen fuel in vehicles. Safety measures at hydrogen infrastructure facilities. **References: [1], [2], [6].**
11	**Lecture 18.** Topic 3.3. Environmental aspects of the use of hydrogen fuel in road and air transport. **References: [1], [3], [4].**

Practical lessons

No	Tasks to be assigned for practical classes
Practical lesson 1	Study of the principle of electrolyzer operation and study of the process of hydrogen production by electrolysis
Practical lesson 2	Study of the principle of operation of internal combustion engines
Practical lesson 3	Study of the design of a hydrogen-fueled internal combustion engine
Practical lesson 4	Evaluation of performance indicators of cars equipped with hydrogen engines
Practical lesson 5	Study of the structure, principle of operation and main types of fuel cells
Practical lesson 6	Study of the storage systems for gaseous and liquid hydrogen on board aircraft
Practical lesson 7	Evaluation of the volume and mass characteristics of hydrogen storage tanks on board aircraft
Practical lesson 8	Study of the hydrogen storage systems in metal hydrides
Practical lesson 9	Interaction of hydrogen with structural materials and safety measures for its storage and transportation Modular control work

6. Student's self-study

Student's self-study include:

Preparation for classroom lessons - 56 hours;

Preparation to module control work – 2 hours;

Preparation to credit – 8 hours.

Policy and control

7. Policy of the academic discipline (educational component)

At the time of each lesson, both lecture and practical, the student must have the Google meet application installed on the device from which he or she is working (in the case of distance learning), and the course "Hydrogen Transport Technologies" on the Sikorsky platform (the access code to the course is provided at the first lesson according to the schedule). Silabus; lecture material; assignments for each practical lesson; variants of the module test; guidelines for practical work and calculation and graphic work; variants of the final test are available on the Sikorsky platform and in the KPI Electronic Campus system.

While taking the course "Hydrogen Transport Technologies", students are obliged to adhere to the general moral principles and rules of ethical behavior specified in the Code of Honor of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

The deadlines for each assignment are specified in the course "Hydrogen Transportation Technologies" on the Sikorsky platform.

All students, without exception, are obliged to comply with the requirements of the Regulations on the system of prevention of academic plagiarism at the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute".

For participating in the All-Ukrainian Olympiad (research paper competition), a student is awarded 5 (I round) or 10 (II round) points. For writing an article and publishing it, a student is awarded 10 points (a publication included in Scopus or Web of Science) or 6 points (a professional publication of Ukraine). For publishing abstracts at a scientific conference, 3 points are awarded. The total amount of incentive points cannot exceed 10 points.

8. Types of control and rating system for assessing learning outcomes (RSA)

Current control: assignments within the framework of practical classes (9 practical classes × 10 points = 90 points), MCW (conducted directly at the practical class, in the presence of the teacher, 10 points). At the end of the lesson, the test is closed and cannot be rewritten or completed at home. The test contains twenty questions and several answers to each of them, one of which is correct. Each correct answer is worth 0.5 points.

The tasks within the practical and laboratory classes are evaluated in 5 points according to the following criteria:

- "excellent" - a complete answer (at least 90% of the required information), appropriate justifications and personal opinion are provided - 10 points;
- "good" - a sufficiently complete answer (at least 75% of the required information), which is performed in accordance with the requirements for the "skills" level or contains minor inaccuracies – 9-8 points;
- "satisfactory" - an incomplete answer (at least 60% of the required information), performed in accordance with the requirements for the "stereotypical" level and containing some errors – 7-5 points;
- "unsatisfactory" - unsatisfactory answer - 0-2 points.

Calendar control: is conducted twice a semester as a monitoring of the current state of fulfillment of the requirements of the sila-bus. The condition for a positive first and second calendar control is to obtain at least 50% of the maximum possible rating at the time of the relevant calendar control.

Semester control: credit. Conditions for admission to the semester control: completed and credited practical works and MCW. Students who have fulfilled all the conditions for admission to the test and have a rating score of 60 or more points receive a grade corresponding to the rating without additional tests. The sum of the rating points received by the student during the semester is transferred to the final grade according to the table. If the sum of points is less than 60, but practical works and ICR are completed and credited, the student performs a test work. In this case, the sum of points for practical, ICR and test work is transferred to the final grade according to the table. A student who has received more than 60 points in a semester but wishes to improve his or her result may take part in the test work. In this case, the final result consists of the points obtained in the test work and the points for practical and internship work.

The test is worth 40 points. The test task of this paper consists of three theoretical questions from the list provided in the appendix to the syllabus.

Each question and task is worth 13 points (if you get 39 points for each question, 1 point is added to the grade) according to the following criteria

- "excellent" - a complete answer (at least 90% of the required information), appropriate justifications and personal opinion are provided - 13 - 11 points;
- "good" - a sufficiently complete answer (at least 75% of the required information), which is made in accordance with the requirements for the "skills" level or contains minor inaccuracies - 12 - 10 points;
- "satisfactory" - an incomplete answer (at least 60% of the required information), performed in accordance with the requirements for the "stereotypical" level and containing some errors - 9 - 7 points;
- "unsatisfactory" - unsatisfactory answer - 0 points.

Table of correspondence between rating points and grades on the university scale:

Number of points	Grade
100-95	Excellent
94-85	Very good
84-75	Good
74-65	Satisfactory
64-60	Sufficient
Below 60	Non-satisfactory
The conditions for admission are not met	Not admitted

9. Additional information on the discipline (educational component)

The list of questions submitted for semester control is given in the appendix to the syllabus.

A higher education applicant has the opportunity to take an online course(s) on one or more topics provided by the work program of the discipline. An applicant can choose an online course independently or on the recommendation of a teacher. 1 hour of the course is evaluated at 0.83 points. The maximum number of hours that can be credited for the results of non-formal education is 12 hours, respectively, the maximum number of points for such results is 10 points.

Work program of the discipline (Syllabus):

Developed by associate professor, PhD, senior researcher, Anna V. Yakovlieva

Approved by the department of automaton of eletrotechnic and mechatronic complexes, minutes No 17 from 31.05.23p.

Approved by methodic council of the ES IESEM, minutes No 9 from 22.06.23 p.

Appendix to the syllabus of the educational component
"Digital and nonlinear control systems of electrical engineering complexes"
List of tasks to be submitted for semester control

1. Describe the principle of operation of the electrolyzer
2. Describe the features of cryogenic hydrogen storage
3. Describe the infrastructure for the use of hydrogen
4. Describe the state of development of hydrogen energy in Ukraine
5. Features of operation and application of high temperature fuel cells
6. Give directions of hydrogen use in aviation
7. Explain the features of the use of hydrogen fuel mixtures in internal combustion engines
8. Describe the storage of hydrogen in compressed form
9. Describe the process of hydrogen production by steam conversion of methane
10. Features of the use of fuel cells on board aircraft
11. Describe the storage of hydrogen in metal hydrides or their alloys
12. Describe the process of hydrogen production by coal gasification
13. Describe the features of hydrogen use in internal combustion engines of cars
14. Describe the storage of hydrogen in carbon nanomaterials
15. Features of the use of hydrogen in gas turbine engines of aircraft
16. Describe the processes of destruction of metals by hydrogen
17. Describe the concepts of "gray hydrogen", "blue hydrogen", "green hydrogen", "pink hydrogen"
18. Describe the storage of hydrogen in organic liquids
19. Describe the processes of destruction of polymeric materials under the influence of hydrogen
20. Describe the storage of hydrogen in the form of soluble salts
21. Give the main threats associated with the storage of compressed hydrogen
22. What are the main types of electrolizers you know. What are their differences?
23. What are the main threats associated with the storage of hydrogen in metal hydrides?
24. Application of hybrid hydrogen power plants in aviation
25. Features of operation and application of low-temperature fuel cells
26. Describe the process of hydrogen production by biomass gasification
27. Describe the process of hydrogen production by steam conversion of methane
28. Describe the principle of operation of the fuel cell
29. Describe the features of cryogenic hydrogen storage