

TURBINSKI STROJI

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Turbinski stroji
Course title:	Turbomachinery
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Energetsko strojništvo (smer)	1. letnik	2. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566856
Koda učne enote na članici/UL Member course code:	6004-M

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorials	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individual student work	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	prof. dr. Marko Hočevar, doc. dr. Lovrenc Novak
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Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Energetsko strojništvo, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Energy engineering, which is an elective specialised course in other fields of study.
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Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:

Prerequisites:

Izpolnjevanje pogojev za vpis v Magistrski študijski program II. stopnje Strojništvo - Razvojno raziskovalni program.	Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.
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Vsebina:

Content (Syllabus outline):

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1. Predavanje: Uvod: potek dela, obveznosti študentov, zgodovina in pomen turbinskih strojev za človeka in družbo, pregled slovenskih podjetij, ki proizvajajo turbine stroje. 2. Predavanje: Osnove delovanja turbinskih strojev: pregled pristopov k razlagi turbinskih strojev (termodinamski, kontrolni volumen, CFD, Eulerjev itd.), razvrstitev turbinskih strojev glede na različne kriterije odprt/zaprt, fizikalno delovanje, uporabo, smer pretvorbe energije, smer toka itd. 3. Predavanje: Prvi zakon termodinamike za turbine stroje: izkoristki turbinskih strojev, izkoristki vodnih, plinskih in parnih turbin, izkoristki črpalk in ventilatorjev, oblika karakteristične krivulje delovnih in pogonskih turbinskih strojev, izgube v pretočnem traktu turbinskih strojev (puščanje na vrhu lopatice, odlepljanje toka na robu, odlepljanje toka na vstopnem robu, udarne izgube, vstopne izgube, vrtnice za gonilnikom, izgube na steni itd. 4. Predavanje: Pristop kontrolnega volumna: kontinuitetna in gibalna enačba, vrtilna količina, energija, dinamično in stacionarno delovanje turbinskih strojev. 5. Predavanje: Diferencialni pristop: kontinuitetna in gibalna enačba, uporaba za izračun toka v turbinskih strojih. 6. Predavanje: Tok tekočine turbinskih strojih 1: 1. in 2. Eulerjeva enačba, razlaga posameznih členov Eulerjeve enačbe in pomen za dizajn in uporabo, trikotniki hitrosti, pretvorba hitrosti, entalpije in tlaka v turbinskih strojih (aksialni, radialni, turbine, ventilatorji), karakteristika in školjčni diagram, povezava z obliko lopatic. 7. Predavanje: Tok tekočine turbinskih strojih 2: oblika lopatic vodilnika, gonilnika in difuzorja, reaktivnost turbinskih strojev, vpliv kota lopatic na reaktivnost, totalni, statični in dinamični tlak v odvisnosti od kota lopatic. 8. Predavanje: Radialni turbinski stroji 1: Eulerjeva enačba, karakteristika radialnih turbinskih strojev, vpliv oblike lopatic na totalni in statični tlak ter moč, vpliv izgub v radialnih turbinskih strojih na obliko karakteristike. 9. Predavanje: Radialni turbinski stroji 2: vpliv števila lopatic na delovanje turbinskih strojev, vrtnenje toka v pretočnih kanalih, povezava z izgubami, karakteristika ventilatorjev z velikim številom naprej zakrivljenih lopatic.	1. Lecture: Introduction: workflow, student obligations, history and importance of turbine machinery for society, review of Slovenian turbine machines companies. 2. Lecture: Fundamentals of turbine machine operation: an overview of approaches for the interpretation of turbine machines operation (thermodynamic, control volume, CFD, Euler, etc.), classification of turbine machines according to different criteria: open/closed, physical operation, use, the direction of energy conversion, the direction of flow, etc. 3. Lecture: The first law of thermodynamics for turbine machines: efficiency of turbine machines, the efficiency of water, gas and steam turbines, efficiency of pumps and fans, shape of the characteristic curve of working and propulsion turbine machines, losses in the flow tract of turbine machines (leakage at the top of the blade, tip vortex, leading-edge vortex, impact losses, entry losses, draft tube vortex, wall losses, etc). 4. Lecture: Control volume approach: continuity and equation of motion, angular momentum, energy, transient and stationary operation of turbine machines. 5. Lecture: Differential approach: continuity and equation of motion, use for calculating the flow in turbine machines. 6. Lecture: The fluid flow of turbine machines 1: 1st and 2nd form of Euler equation, explanation of individual terms of Euler equation and importance for design and use, velocity triangles, velocity, enthalpy and pressure conversion in turbine machines (axial, radial, turbines, fans), characteristic and hill diagram, relation to the shape of the blades. 7. Lecture: The fluid flow of turbine machines 2: blade shape of the guide vanes, runner and diffuser, reactivity of turbine machines, the influence of blade angle on reactivity, total, static and dynamic pressure depending on blade angle. 8. Lecture: Radial turbine machines 1: Euler equation, characteristic of radial turbine machines, the influence of blade shape on total and static pressure and power, influence of losses in radial turbine machines on the characteristic curve shape. 9. Lecture: Radial turbine machines 2: Influence of the number of blades on the operation of the turbine machines, vorticity in flow channels, connection with losses, characteristic
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10. Predavanje: Aksialni turbinski stroji: Eulerjeva enačba, reaktivnost, konfiguracije aksialnih turbinskih strojev vodilnik/gonilnik, izguba vzgona na lopaticah, stall. 11. Predavanje: Teorija podobnosti: uporaba v turbinskih strojih, tlačno, pretočno in močnostno število, uporaba brezdimenzijskih števil, specifična hitrost, Cordierov diagram. 12. Predavanje: Načrtovanje oblike lopatic turbinskega stroja: primer načrtovanja aksialnega ventilatorja za vgradnjo v klimatske sisteme, določitev delovne točke, izbira profila lopatic, osnove načrtovanja v programu OpenFoam. 13. Predavanje: Proizvodnja ventilatorjev: opis načina proizvodnje ventilatorjev, izdelava lopatic za različne tipe turbinskih strojev, izdelava pesta, ohišja in mrežice, vgradnja elektromotorja ali drugega pogona, balansiranje. 14. Predavanje: Propelerji in ladijski vijaki: potisk, upor ladje in letala, hod in slip, koeficient potiska, koeficient navora, koeficient relativnega napredovanja, družina propelerjev Wageningen, propelerski diagram, vpliv števila lopatic, napredovanja in površine lopatic vijaka ali propelerja. 15. Predavanje: Alternativna področja uporabe turbinskih strojev: medicina, biotehnologija, čiščenje odpadnih vod, kontaminanti v toku.	of fans with a large number of forward curved blades. 10. Lecture: Axial turbine machines: Euler equation, reactivity, axial turbine machine configurations guide vanes/runner, surge, stall. 11. Lecture: Theory of similarity: use in turbine machines, pressure, flow and power numbers, use of dimensionless numbers, specific speed, Cordier diagram. 12. Lecture: Design of turbine machine blades: an example of axial fan design for installation in air-conditioning systems, determination of operating point, selection of blade profile, basics of design in OpenFoam. 13. Lecture: Fan production: a description of the fan production methods, production of blades for different types of turbine machines, hub, casing and net, installation of an electric motor or other drives, balancing. 14. Lecture: Propellers and screws: thrust, ship and aircraft resistance, pitch and slip, thrust coefficient, torque coefficient, relative advance coefficient, Wageningen propeller family, propeller diagram, the influence of the number of blades, advance ratio and the surface of blades of the propeller. 15. Lecture: Alternative application of turbine machines: medicine, biotechnology, wastewater treatment, contaminants in flow.
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Temeljna literatura in viri/Readings:

1. Marko Hočvar in Matevž Dular, Uvod v hidroenergetske sisteme, Fakulteta za strojništvo, učbenik, [COBISS.SI-ID [282771968](#)], 2015
2. Eck, Bruno. Ventilatoren : Entwurf und Betrieb der Radial-, Axial- und Querstromventilatoren. Springer, [COBISS.SI-ID [12016133](#)], 1991
3. Dixon, S. L., Hall, C. A., Fluid Mechanics and thermodynamics of turbomachinery, Elsevier, [COBISS.SI-ID [26840325](#)], 2005

Cilji in kompetence:

Cilji: 1. Spoznati princip delovanja turbinskih strojev. 2. Spoznati osnovne gradnike turbinskih strojev. 3. Razumeti energijske pretvorbe v turbinskih strojih. 4. Razumeti spreminjanje tlaka in hitrosti po posameznih elementih turbinskih strojev. 5. Spoznati način izdelave in obratovanja turbinskih strojev. Kompetence:	Objectives and competences: Objectives: 1. To learn the principle of operation of turbine machines. 2. Know the basic building blocks of turbine machines. 3. Understand energy conversion in turbine machines. 4. Understand the variation of pressure and velocity by individual elements of turbine machines.
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1. S2-MAG: Sposobnost samostojne izbire in uporabe turbinskega stroja za potrebe posamezne naloge ali aplikacije. 2. P2-MAG Sposobnost razumevanja interakcije turbinskega stroja z energetske ali procesnim sistemom. 3. P4-MAG Sposobnost razvoja novega turbinskega stroja ali družine turbinskih strojev. 4. P6-MAG Sposobnost sprejemanja odločitev v energetskih in procesnih sistemih, ki se nanašajo na turbine stroje. 5. P7-MAG Sposobnost diagnosticiranja posebnosti in napak delovanja turbinskih strojev ter njihovo odpravljanje.	5. To learn how to make and operate turbine machines. Competencies: 1. S2-MAG: Ability to independently select and use a turbine machine for the needs of a particular task or application. 2. P2-MAG The ability to discuss the interaction of a turbine machine with an energy or process system. 3. P4-MAG Ability to develop a new turbine machine or family of turbine machines. 4. P6-MAG The ability to make decisions in energy and process systems related to turbine machines. 5. P7-MAG Ability to diagnose and troubleshoot operation of turbine machines.
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Predvideni študijski rezultati:

Znanja: Z2: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja, ki je osnova za zelo zahtevno znanstveno in strokovno delo na področju sinteze, načrtovanja, uporabe in napovedovanja delovanja turbinskih strojev. Spretnosti: S2.1: Priprava kompleksnih eksperimentov za dokazovanje karakteristike in izkoristka turbinskih strojev v energetskih in procesnih sistemih. S2.2: Uporaba modernih metod za načrtovanje in analizo obnašanja turbinskih strojev v realnih obratovalnih razmerah.	Knowledge: Z2: In-depth theoretical, methodological and analytical knowledge with elements of research, which is the basis for very demanding scientific and professional work in the field of synthesis, design, use, and prediction of the operation of turbine machines. Skills: S2.1: Preparation of complex experiments to demonstrate the characteristics and efficiency of turbine machines in power and process systems. S2.2: Application of modern methods for the design and analysis of the behavior of turbine machines under real operating conditions.
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Metode poučevanja in učenja:

Klasične oblike poučevanja: P1: Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. P2: Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri in razlago, potrebno za razumevanje laboratorijskih vaj. P3: Laboratorijske vaje z namenski didaktični pripomočki kot so gradniki merilne postaje, različni turbinski stroji, loputami, frekvenčni pretvorniki,	Classical forms of teaching: P1: Lectures with solving selected - typical and practical examples. P2: Tutorials, where theoretical knowledge of the lectures is supported by analytical and computational examples and explanations needed to understand the lab work. P3: Laboratory exercises with dedicated didactic devices such as measuring station building blocks, various turbine machines, frequency converters, flaps, flow meters, temperature, relative humidity, pressure, electrical power meters, etc.
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Learning and teaching methods:

merilniki pretoka, temperature, relativne vlažnosti, tlaka, električne moči itd. Moderne in prožne oblike poučevanja: P4: Uporaba študijskega slikovnega in filmskega gradiva za predstavitev delovanja, uporabe in proizvodnje turbinskih strojev. P5: Uporaba študijskega gradiva kot so modeli računalniške dinamike tekočin s predstavitvijo geometrijske oblike turbinskih strojev, tlačnega in hitrostnega polja ter tokovnic z odprtokodno programsko opremo za analizo podatkov in vizualizacijo (npr. Paraview). P6: Študij literature in razprava. P7: Skupinsko delo, razprava, strukturirana diskusija med laboratorijskimi vajami in ekskurzijami. P8: Virtualni eksperimenti za določanje karakteristike turbinskih strojev.	Modern and flexible forms of teaching: P4: Use of image and movie materials to demonstrate, operate, and produce turbine machines. P5: Use of study materials such as models of computational fluid dynamics by presenting the geometric shape of turbine machines, pressure and velocity fields, and open source software for data analysis and visualization (eg Paraview). P6: Literature studies and discussion. P7: Group work, discussion, the structured discussion between lab work and field trips. P8: Virtual experiments to determine the characteristics of turbine machines.
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Načini ocenjevanja:	Delež/Weight	Assessment:
- kolokvij pri laboratorijskih vajah	50,00 %	- laboratory exam
- izpit	50,00 %	- exam

Ocenjevalna lestvica:	Grading system:
5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10	5 - 10, a student passes the exam if he is graded from 6 to 10

Reference nosilca/Lecturer's references:

Marko Hočevar:

- NOVAKOVIĆ, Tadej, ČUROVIĆ, Luka, **HOČEVAR, Marko**, PREZELJ, Jurij. Impact of geometric modifications of small axial fans on psychoacoustic metrics. Applied acoustics. Mar. 2024, vol. 218, [article no.] 109913, str. 1-15, ilustr. ISSN 1872-910X.
<https://www.sciencedirect.com/science/article/pii/S0003682X24000641>, DOI: [10.1016/j.apacoust.2024.109913](https://doi.org/10.1016/j.apacoust.2024.109913). [COBISS.SI-ID [184900611](#)].
- ZUPANC, Mojca, BRAJER HUMAR, Barbara, DULAR, Matevž, GOSTIŠA, Jurij, **HOČEVAR, Marko**, KOLBL REPINC, Sabina, KRZYK, Mario, NOVAK, Lovrenc, ORTAR, Jernej, PANDUR, Žiga, STRES, Blaž, PETKOVŠEK, Martin. The use of hydrodynamic cavitation for waste-to-energy approach to enhance methane production from waste activated sludge. Journal of environmental management. Dec. 2023, vol. 347, str. 1-11, ilustr. ISSN 0301-4797.
<https://www.sciencedirect.com/science/article/pii/S0301479723018625>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=151587>, DOI: 10.1016/j.jenvman.2023.119074. [COBISS.SI-ID [167876867](#)].
- OMAN, Simon, NAGODE, Marko, KLEMENC, Jernej, MAJDIČ, Franc, **HOČEVAR, Marko**, GOSAR, Aleš, ŠKRLEC, Andrej, OLAH, Laslo. Submersible pump assembly and method for use of same : United States patent US 10,883,488 B1, 2021-01-05. Alexandria: United States Patent and Trademark Office, 2021. 10 f., ilustr. [COBISS.SI-ID [46897667](#)].
- NOVAK, Lovrenc, PETKOVŠEK, Martin, OMAN, Simon, NAGODE, Marko, KLEMENC, Jernej, MAJDIČ, Franc, **HOČEVAR, Marko**, GOSAR, Aleš, OLAH, Laslo. Downhole three phase separator and method for use of same : United States Patent US 11,143,009 B1, 2021-10-12. Alexandria (VA):

United States Patent and Trademark Office, 2021. [12] f., ilustr. <https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=1&f=G&l=50&co1=AND&d=PTXT&s1=Oman.INNM.&OS=IN/Oman&RS=IN/Oman>, <https://worldwide.espacenet.com/patent/search/family/078007966/publication/US11143009B1?q=pn%3DUS11143009B1>. [COBISS.SI-ID 73371651].

5. VAGNONI, Elena, GEZER, Dogan, ANAGNOSTOPOULOS, Ioannis, CAVAZZINI, Giovanna, DOUJAK, Eduard, **HOČEVAR, Marko**, RUDOLF, Pavel. The new role of sustainable hydropower in flexible energy systems and its technical evolution through innovation and digitalization. V: 36th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2023) : 25-30 June 2023, Las Palmas de Gran Canaria, Spain. [S. l.]: ECOS: Curran Associates, 2023. Str. 1767-1776. ilustr. ISBN 978-1-7138-7492-8, [COBISS.SI-ID [176354563](#)].

Lovrenc Novak:

1. PODNAR, Andrej, HOČEVAR, Marko, **NOVAK, Lovrenc**, DULAR, Matevž. Analysis of bulb turbine hydrofoil cavitation. *Applied sciences*. Mar. 2021, vol. 11, iss. 6, str. 1-18, ilustr. ISSN 2076-3417. <https://www.mdpi.com/2076-3417/11/6/2639>, [Repozitorij Univerze v Ljubljani – RUL](#), DOI: [10.3390/app11062639](https://doi.org/10.3390/app11062639). [COBISS.SI-ID [56988419](#)]
2. **NOVAK, Lovrenc**, BAJCAR, Tom, ŠIROK, Brane, ORBANIĆ, Alen, BIZJAN, Benjamin. Investigation of vortex shedding from an airfoil by CFD simulation and computer-aided flow visualization. *Thermal science*. 2018, vol. 22, iss. 6, str. 3023-3033, ilustr. ISSN 0354-9836. <http://thermalscience.vinca.rs/online-first/2732>, [Repozitorij Univerze v Ljubljani – RUL](#), DOI: [10.2298/TSCI170615002N](https://doi.org/10.2298/TSCI170615002N). [COBISS.SI-ID [15955995](#)]
3. ZUPANC, Mojca, BRAJER HUMAR, Barbara, DULAR, Matevž, GOSTIŠA, Jurij, HOČEVAR, Marko, KOLBL REPINC, Sabina, KRZYK, Mario, **NOVAK, Lovrenc**, ORTAR, Jernej, PANDUR, Žiga, STRES, Blaž, PETKOVŠEK, Martin. The use of hydrodynamic cavitation for waste-to-energy approach to enhance methane production from waste activated sludge. *Journal of environmental management*. Dec. 2023, vol. 347, str. 1-11, ilustr. ISSN 0301-4797. <https://www.sciencedirect.com/science/article/pii/S0301479723018625>, [Repozitorij Univerze v Ljubljani – RUL](#), DOI: [10.1016/j.jenvman.2023.119074](https://doi.org/10.1016/j.jenvman.2023.119074). [COBISS.SI-ID [167876867](#)]
4. HOČEVAR, Marko, **NOVAK, Lovrenc**, DREŠAR, Primož, RAK, Gašper. The status quo and future of hydropower in Slovenia. *Energies*. sept. 2022, vol. 15, iss. 19, art. 6977, 13 str., ilustr. ISSN 1996-1073. <https://www.mdpi.com/1996-1073/15/19/6977>, [Repozitorij Univerze v Ljubljani – RUL](#). [COBISS.SI-ID [123711491](#)]
5. HOČEVAR, Marko, **NOVAK, Lovrenc**, RAK, Gašper. Future needs for energy storage in the alpine region = Prihodnje potrebe po shranjevanju energije v alpskem prostoru. *Acta hydrotechnica*. [Spletna izd.]. 2019, letn. 32, št. 56, str. 35-43, ilustr. ISSN 1581-0267. <ftp://ksh.fgg.uni-lj.si/acta/a32mh.pdf>, [Repozitorij Univerze v Ljubljani – RUL](#), [Digitalna knjižnica Slovenije – dLib.si](#), DOI: [10.15292/acta.hydro.2019.03](https://doi.org/10.15292/acta.hydro.2019.03). [COBISS.SI-ID [8908897](#)]