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
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Energetsko strojništvo (smer)	1. letnik	2. semester

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

Predavanja	Seminar	Vaje	Klinične vaje	Druge oblike študija	Samostojno delo	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	Lovrenc Novak, Marko Hočevar
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.

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.

Vsebina:	Content (Syllabus outline):
1. Predavanje: Uvod: potek dela, obveznosti študentov, zgodovina in pomen turbinskih strojev za človeka in družbo, pregled slovenskih podjetij, ki proizvajajo turbinske stroje. 2. Predavanje: Osnove delovanja turbinskih strojev:	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

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 turbinske 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, vrtinec 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, vrtinčenje toka v pretočnih kanalih, povezava z izgubami, karakteristika ventilatorjev z velikim številom naprej zakrivljenih lopatic.
10. Predavanje: Aksialni turbinski stroji: Eulerjeva enačba, reaktivnost, konfiguracije akasialnih 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

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 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,

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.	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.

Temeljna literatura in viri/Readings:

1. Marko Hočevar, Introduction to turbine machinery, Fakulteta za strojništvo, učbenik, 2019
2. Eck, Bruno. Fans. 1st English ed., Pergamon Press, Oxford, 1973
3. Dixon, S. L., Hall, C. A., Fluid Mechanics and thermodynamics of turbomachinery, Elsevier, 2010

Cilji in kompetence:	**Objectives and competences:**
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: 1. S2-MAG: Sposobnost samostojne izbire in uporabe turbinskega stroja za potrebe posamezne naloge ali aplikacije. 2. P2-MAG Sposobnost razmevanja interakcije turbinskega stroja z energetskim 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	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. 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.

na turbinske stroje. 5. P7-MAG Sposobnost diagnosticiranja posebnosti in napak delovanja turbinskih strojev ter njihovo odpravljanje.	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.

Predvideni študijski rezultati:	**Intended learning outcomes:**
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.

Metode poučevanja in učenja:	**Learning and teaching methods:**
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 namenskimi didaktičnimi pripomočki kot so gradniki merilne postaje, različni turbinski stroji, loputami, frekvenčni pretvorniki, 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).	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. 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: Študij literature in razprava. P7: Skupinsko delo, razprava, strukturirana diskusija med laboratorijskimi vajami in ekskurzijami. P8: Virtualni eksperimenti za določanje karakteristike turbinskih strojev.	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.

Načini ocenjevanja:	**Delež/Weight**	**Assessment:**
sodelovanje pri laboratorijskih vajah	15,00 %	participation in lab work
poročila o laboratorijskih vajah	10,00 %	lab report
kolokvij pri laboratorijskih vaja	25,00 %	laboratory exams
izpit	50,00 %	exam

Reference nosilca/Lecturer's references:

Marko Hočevar

1. Podnar Andrej, Dular Matevž, Širok Brane, Hočevar Marko. Experimental analysis of cavitation phenomena on kaplan turbine blades using flow visualization. Journal of fluids engineering : Transactions of the ASME. Jul. 2019, vol. 141, iss. 7, str. 1-13
2. Malneršič Aleš, Dular Matevž, Širok Brane, Oberti Roberto, Hočevar Marko. Close-range air-assisted precision spot-spraying for robotic applications : aerodynamics and spray coverage analysis. Biosystems engineering, Jun. 2016, vol. 146, str. 216-226.
3. Bizjan Benjamin, Milavec Matej, Širok Brane, Trenc Ferdinand, Hočevar Marko. Energy dissipation in the blade tip region of an axial fan. Journal of sound and vibration, Nov. 2016, vol. 382, str. 63-72
4. Milavec Matej, Širok Brane, Vidal De VentóS Daniel, Hočevar Marko. Identification of noise generation and flow kinematics in the air gap for two different blade tip designs of an axial fan. Forschung im Ingenieurwesen, Jun. 2015, vol. 79, iss. 1, str. 29-39.
5. Cencič Tine, Hočevar Marko, Širok Brane. Study of erosive cavitation detection in pump mode of pump-storage hydropower plant prototype. Journal of fluids engineering : Transactions of the ASME. May 2014, vol. 136, no. 5, str. 051301-1-051301-11

Lovrenc Novak

1. PODNAR, Andrej, HOČEVAR, Marko, **NOVAK, Lovrenc**, DULAR, Matevž. Analysis of bulb turbine hydrofoil cavitation. *Applied sciences*, ISSN 2076-3417, Mar. 2021, vol. 11, iss. 6, str. 1-18, ilustr. https://www.mdpi.com/2076-3417/11/6/2639, doi: 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*, ISSN 0354-9836, 2018, vol. 22, iss. 6, str. 3023-3033, ilustr. http://thermalscience.vinca.rs/online-first/2732, doi: 10.2298/TSCI170615002N. [COBISS.SI-ID 15955995]
3. MORI, Mitja, DROBNIČ, Boštjan, JURJEVČIČ, Boštjan, **NOVAK, Lovrenc**. Numerical modeling of heat transfer and flow phenomena in an axial rotating rotor cascade. *Numerical heat transfer. Part A, Applications*, ISSN 1040-7782. [Print ed.], 2015, vol. 67, iss. 10, str. 1053-1074, ilustr., doi: 10.1080/10407782.2014.955355. [COBISS.SI-ID 13861403]
4. SEKAVČNIK, Mihael, MORI, Mitja, **NOVAK, Lovrenc**, SMREKAR, Jure, TUMA, Matija. Heat transfer evaluation method in complex rotating environments employing IR thermography and CFD. *Experimental heat transfer*, 2008, letn. 21, št. 2, str. 155-168. http://dx.doi.org/10.1080/08916150701815770. [COBISS.SI-ID 10427163]
5. MORI, Mitja, **NOVAK, Lovrenc**, SEKAVČNIK, Mihael, KUŠTRIN, Igor. Application of IR thermography as a measuring method to study heat transfer on rotating surface. *Forschung im Ingenieurwesen*, ISSN 0015-7899, 2008, vol. 72, iss. 1, str. 1-10, doi: 10.1007/s10010-007-0062-8. [COBISS.SI-ID 10473499]

6. **NOVAK, Lovrenc**, MORI, Mitja, SEKAVČNIK, Mihael. Heat transfer study in rotating cascade using IR thermography and CFD analyses. *Heat and mass transfer*, ISSN 0947-7411, 2008, vol. 44, no. 5, str. 559-567. http://dx.doi.org/10.1007/s00231-007-0269-0. [COBISS.SI-ID 10122011]
7. MORI, Mitja, **NOVAK, Lovrenc**, SEKAVČNIK, Mihael. Measurements on rotating blades using IR thermography. *Experimental thermal and fluid science*, ISSN 0894-1777. [Print ed.], 2007, letn. 32, št. 2, str. 387-396. http://dx.doi.org/10.1016/j.expthermflusci.2007.05.002. [COBISS.SI-ID 10121755]
8. MORI, Mitja, **NOVAK, Lovrenc**, SEKAVČNIK, Mihael. Konvektivni prenos toplote v vrtečem kanalu kaskade z ravnimi lopaticami = Convective heat transfer inside rotational cascades with flat blades. *Strojniški vestnik*, ISSN 0039-2480, 2003, letn. 49, št. 9, str. 445-457. [COBISS.SI-ID 6795035]