EKSPERIMENTALNE METODE V ENERGETSKEM STROJNIŠTVU

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Eksperimentalne metode v energetskem strojništvu
Course title:	Experimental Methods in Energy Engineering
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	**Študijska smer**	**Letnik**	**Semestri**	**Izbirnost**
Strojništvo - projektno aplikativni program, prva stopnja, visokošolski strokovni (od študijskega leta 2025/2026 dalje)	Energetsko strojništvo (smer)	2. letnik	2. semester	obvezni

Univerzitetna koda predmeta/University course code:	0562722
Koda učne enote na članici/UL Member course code:	3025-V

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			40	4

Nosilec predmeta/Lecturer:	Andrej Svete, Jože Kutin, Marko Hočevar

Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	

Izvajalci praktičnega usposabljanja:	
Vrsta predmeta/Course type:	Izbirni strokovni predmet/Elective specialised course

Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	**Prerequisites:**
Izpolnjevanje pogojev za vpis v Visokošolski strokovni študijski program I. stopnje Strojništvo - Projektno aplikativni program.	Meeting the enrollment conditions for the MECHANICAL ENGINEERING - Project Oriented Applied Programme.

Vsebina:	**Content (Syllabus outline):**
1. Uvod - Pomen preskušanj in drugih področij eksperimentalnega dela v energetskem strojništvu - Pregled značilnih preskušanih naprav in sistemov - Pregled pomembnejših fizikalnih veličin, ki jih treba meriti oz. nadzorovati 2. Tehnične zahteve za obvladovanje eksperimentalnega dela 1 - Pregled standardnih zahtev za obvladovanje preskušanj in drugih področij eksperimentiralnega dela - Zahteve glede usposobljenosti osebja - Izbira in validacija preskusnih metod in postopkov 3. Tehnične zahteve za obvladovanje eksperimentalnega dela 2 - Obvladovanje merilne in programske opreme - Obvladovanje okoljskih pogojev - Zapisi in poročanje o rezultatih 4. Eksperimentalni procesi s tlakom kot merjeno veličino 1 - Opredelitev tlaka kot merjene veličine - Pregled merilnih metod za tlak - Pregled sistemov za nadzor tlaka	1. Introduction - Purpose of testing and other fields of experimental work in energy engineering - Review of typical devices and systems under test - Review of most important physical quantities that should be measured or controlled 2. Technical requirements for management of experimental work 1 - Review of standard requirements for management of testing and other fields of experimental work - Requirements for qualification of personnel - Selection and validation of testing methods and procedures 3. Technical requirements for management of experimental work 2 - Management of measuring and programming equipment - Management of surrounding conditions - Records and reporting of results 4. Experimental processes with pressure as measured quantity 1 - Defining pressure as measured quantity

5. Eksperimentalni procesi s tlakom kot merjeno veličino 2 - Vplivni dejavniki pri merjenju tlaka - Izvedba odjema tlaka in tlačnih povezav - Korekcija vpliva višinske razlike 6. Eksperimentalni procesi s temperaturo kot merjeno veličino 1 - Opredelitev temperature kot merjene veličine - Pregled merilnih metod za merjenje temperature - Pregled sistemov za nadzor temperature 7. Eksperimentalni procesi s temperaturo kot merjeno veličino 2 - Vplivni dejavniki na dotikalno merjenje temperature v tekočinah, na površinah - Vplivi toplotnih izgub - Vplivi dinamičnih lastnosti merilnega sistema 8. Eksperimentalni procesi s temperaturo kot merjeno veličino 3 - Vplivni dejavniki na področju sevalne termometrije - Vplivi lastnosti merjene površine - Vplivi prenosa toplotnega sevanja in motilnih izvorov 9. Postopki merjenja energetskih sistemov: terenske in laboratorijske meritve, opis štirih kategorij postaj v skladu s standardom načina strojev, vloga pomožnih strojev, dušilnih loput, usmerjevalnikov in umirjevalnikov toka, določanje statičnega in dinamičnega tlaka ter izgub. 10. Merilne postaje: merjenje pretoka, tlaka in izkoristka na merilnih postajah: izbira in vgradnja merilne opreme za pretok, tlak, in izkoristek, izvedba priključitve na merilno postajo, povezovanje v sistem. 11. Pomen in način meritve električne in mehanske moči: merjenje navora, moči in električnih spremeljivk, metode za merjenje navora, vrtilne frekvence in mehanske moči, izvedba uležajenja, primeri merjenja na modelu in izvedbi, merjenje električnih spremenljivk (napetost, tok, moč).	- Review of pressure measurement methods - Review of systems for control of pressure 5. Experimental processes with pressure as measured quantity 2 - Influence factors in pressure measurements - Design of a pressure tap and pressure connections - Correction of effects of hydrostatic height 6. Experimental processes with temperature as measured quantity 1 - Defining temperature as measured quantity - Review of temperature measurement methods - Review of systems for control of temperature 7. Experimental processes with temperature as measured quantity 2 - Influence factors in contact temperature measurements in fluids, on solid surfaces - Influences related to heat losses - Influences of dynamic characteristics of the measurement system 8. Experimental processes with temperature as measured quantity 3 - Influence factors in the field of radiation thermometry - Influention properties of measured surface - Influences related to the transmission of thermal radiation and unwanted sources 9. Measurement procedures for energy systems: field and laboratory measurements, description of four categories of measuring stations according to standard, the role of auxiliary machines, dampers, flow straighteners, determination of static and dynamic pressure and losses. 10. Measuring stations: measurement of flow, pressure, and efficiency at measuring stations: selection and installation of measuring equipment for flow, pressure and efficiency, connection to the measuring station, connection to

12. Merjenje lastnosti energetskih strojev na merilnih postajah, povezava z zelenim prehodom, zmanjševanje porabe električne energije in povečanje trajnostnosti. Uvod v digitalne dvojčke v energetskem strojništvu. 13. Karakteristike črpalk in njihovo vključevanje v digitalne dvojčke, modeli lastnosti črpalk, merilne metode za ocenjevanje obratovalnega stanja in preostale življenjske dobe črpalk. 14. Merjenje emisij plinov energetskih sistemov: merilna oprema in postopki za merjenje emisij plinov, ultravijolična fluorescenca, kemiluminiscenca, spektroskopija, plamensko ionizacijska metoda, elektrokemične metode, polprevodniško zaznavalo, merjenje količine preostalega kisika z lambda zaznavalom. Merilni postopki za merjenje emisij delcev. 15. Izvedba merjenja emisij delcev in plinov na energetskih strojih in napravah: primeri uporabe za motorje z notranjim zgorevanjem in v termoelektrarnah.	the system. 11. Importance and method of measurement of electrical and mechanical power: measurement of torque, power and electrical variables, methods for measuring torque, rotational speed and mechanical power, bearing design, examples of measurement on model and prototype, measurement of electrical variables (voltage, current, power). 12. Measuring the properties of energy machines at measuring stations, connection with the green transition, reducing electricity consumption and improving sustainability. Introduction to digital twins in energy engineering. 13. Pump characteristics and their inclusion in digital twins, pump characteristics models, measurement methods for evaluating the operating condition and remaining life of pumps. 14. Measurement of gas emissions of energy systems: measuring equipment and procedures for measuring gas emissions, ultraviolet fluorescence, chemiluminescence, spectroscopy, flame ionization method, electrochemical methods, semiconductor sensor, measurement of the amount of oxygen remaining with the lambda sensor. Measurement of particles emissions. 15. Performance of measurement of particulate and gas emissions on energy machinery and systems: Examples of use for internal combustion engines and thermal power plants.

Temeljna literatura in viri/Readings:

1. Tropea, C., Yarin, A.L., Foss, J.F. (ur.): Springer handbook of experimental fluid mechanics. Springer, 2007 [COBISS.SI-ID 29032965]
2. Michalski, L., Eckersdorf, K., Kucharski, J., McGhee, J.: Temperature measurement. John Wiley & Sons, Chichester, 2001 [COBISS.SI-ID 4853531]
3. Baker, R. C.: Flow measurement handbook: industrial designs, operating principles, performance, and applications. Cambridge University Press, 2000 [COBISS.SI-ID 3809307]
4. Marko Hočevar, Matevž Dular, Diagnostika v okoljskem strojništvu, učbenik, Fakulteta za strojništvo, 2016 [COBISS.SI-ID 286734848]

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Spoznati tehnične zahteve za obvladovanje eksperimentalnega dela v energetskem strojništvu. 2. Spoznati principe merjenj v energetskem strojništvu 3. Spoznati osnovne gradnike merilnih postaj za merjenje karakteristik energetskih strojev in pomen digitalnih dvojčkov in modelov vključevanja gradnikov sistema v digitalne dvojčke 4. Spoznati postopke meritev emisij v energetskem strojništvu Kompetence: 1. S1-PAP + S4-PAP: Sposobnost obvladovanja tehničnih zahtev za eksperimentalno delo 2. P4-PAP: Sposobnost razumevanja delovanja gradnikov merilnih postaj. 3. S7-PAP: Sposobnost sprejemanja odločitev v postopku preskušanja energetskih strojev in naprav. 4. P8-PAP: Sposobnost diagnosticiranja posebnosti v postopku preskušanja energetskih strojev in naprav. 5. S12-PAP: Sposobnost uporabe informacijsko-komunikacijske tehnologije 6. P5-PAP: Pozna glavne okoljske omejitve in probleme 7. P7-PAP: Pozna nekatera potrebna programska orodja za računalniško obdelavo podatkov	Objectives: 1. To familiarize with technical requirements for management of experimental work in energy engineering 2. To familiarize with principles of measurement in energy engineering 3. Get to know the basic components of measuring stations for measuring the characteristics of energy machines and the importance of digital twins and models of integration of system components into digital twins 4. To know the procedures for measuring emissions in energy engineering Competences: 1. S1-PAP + S4-PAP: The ability to manage technical requirements of experimental work 2. P4-PAP: The ability to understand operation of different components of testing systems. 3. S7-PAP: The ability to make decisions in the testing process of energy machines and appliances. 4. P8-PAP: Ability to diagnose specificities in the process of testing power machines and appliances. 5. S12-PAP: The ability to use information and communications technology 6. P5-PAP: Knowing the main environmental restrictions and problems 7. P7-PAP: Knowing some software tools necessary for computer data processing

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Z1: Poglobljeno strokovno teoretično in praktično znanje na določenem področju, podprto s širšo teoretično in metodološko osnovo.	Outcomes: Z1: Thorough professional theoretical and practical knowledge in a selected field of expertise that is supported with a broad theoretical and methodological

• Znanje o področju preskušanja energetskih sistemov in drugem eksperimentalnem delu v energetskem strojništvu. Spretnosti: S1.1 Izvajanje kompleksnih operativno-strokovnih opravil, ki vključujejo tudi uporabo metodoloških orodij. - Načrtovanje merilnih in preskusnih sistemov na področju energetskega strojništva S1.2 Obvladovanje zahtevnih, kompleksnih delovnih procesov ob samostojni uporabi znanja v novih delovnih situacijah. - Obvladovanje modernih merilnih in preskusnih metod za analizo delovanja energetskih strojev in naprav	basis. • Knowledge about testing of energy systems and other experimental work in energy engineering. Skills: S1.1 Executing complex operational-professional tasks that incorporate usage of methodological tools. - Design of measuring and testing systems in the field of energy engineering S1.2 Mastering demanding and complex work processes by independent usage of knowledge in new working situations. - Management of modern measurement and test methods for analyses of operation of energy machines and devices

Metode poučevanja in učenja:	**Learning and teaching methods:**
P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P4 Laboratorijske vaje z namenskimi didaktičnimi pripomočki (postaje za preskušanje različnih energetskih strojev in naprav, merilni sistemi za tlak, temperature in druge merjene veličine, drugi gradniki merilnih in preskusnih postaj). P7 Študij literature in razprava P9 Skupinsko delo P14 Virualni eksperimenti P15 Uporaba video vsebin kot priprava na predavanja in vaje	P1 Auditorial lectures with solving selected field-specific theoretical and applied use cases. P3 Auditorial exercises, in which theoretical content from the lectures is supplemented with practical examples. P4 Laboratory exercises with special-purpose didactic devices (rigs for testing of different energy machines and devices, measuring systems for pressure, temperature and other measured quantites, other components of measurement and test rigs). P7 Literature study and discussion. P9 Team work P14 Virtual experiments. P15 Application of videos for preparations to the lectures and exercises

Načini ocenjevanja:	**Delež/ Weight**	**Assessment:**
Teoretični del (predavanja).	50,00 %	Teoretical part (lectures).

Praktični del (vaje).	50,00 %	Practical part (exercises).
Ustni zagovor predloga ocene.		Oral examination of the proposed grade.

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:

1. RAK, Gašper, **HOČEVAR, Marko**, STEINMAN, Franci. Non-intrusive measurements of free-water-surface profiles and fluctuations of turbulent, two-phase flow using 2-D laser scanner. Measurement science & technology. 2020, letn. , št. , str. 1-14, [COBISS.SI-ID 9074529]
2. RAK, Gašper, STEINMAN, Franci, **HOČEVAR, Marko**, DULAR, Matevž, JEZERŠEK, Matija, PAVLOVČIČ, Urban. Laser ranging measurements of turbulent water surfaces. European journal of mechanics.B, Fluids. feb. 2020, letn. xx, št. xx, str. 1-12, ilustr. [COBISS.SI-ID 9085793]
3. NOVAK, Lovrenc, ŠIROK, Brane, **HOČEVAR, Marko**, GATARIĆ, Pero. Influence of load mass and drum speed on fabric motion and performance of a heat pump tumble dryer. Drying technology. [Print ed.]. 2020, str. 1-15, ilustr., [COBISS.SI-ID 17092379]
4. GATARIĆ, Pero, ŠIROK, Brane, **HOČEVAR, Marko**, NOVAK, Lovrenc. Modeling of heat pump tumble dryer energy consumption and drying time. Drying technology. [Print ed.]. 2019, vol. 37, no. 11, str. 1396-1404, [COBISS.SI-ID 16268571]
5. KHLIFA, Ilyass, VABRE, Alexandre, **HOČEVAR, Marko**, FEZZAA, Kamel, FUZIER, Sylvie, ROUSSETTE, Olivier, COUTIER-DELGOSHA, Olivier. Fast X-ray imaging of cavitating flows. Experiments in fluids. Nov. 2017, vol. 58, str. 1-22, ilustr., [COBISS.SI-ID 15738139]

Jože Kutin:

1. PERUŠKO, Dalibor, KARABAIĆ, Damir, BAJSIČ, Ivan, **KUTIN, Jože**. Ageing of liquified natural gas during marine transportation and assessment of the boil-off thermodynamic properties. Journal of marine science and engineering. Oct. 2023, vol. 11, iss. 10, str. 1-23 [COBISS.SI-ID 168777219], [tipologija 01, JCR]
2. BOBOVNIK, Gregor, MICKAN, Bodo, SAMBOL, Peter, MAURY, Rémy, **KUTIN, Jože**. Investigation of the discharge coefficient in the laminar boundary layer regime of critical flow Venturi nozzles calibrated with different gases including hydrogen. Measurement. Aug. 2023, vol. 217, str. 1-7 [COBISS.SI-ID 154551299], [tipologija 1.01, JCR]
3. **KUTIN, Jože**, SVETE, Andrej. On the theory of the frequency response of gas and liquid pressure measurement systems with connecting tubes. Measurement science & technology, 2018, vol. 29, no. 12, str. 1-11 [COBISS.SI-ID 16293915], [tipologija 1.01, JCR]
4. SVETE, Andrej, **KUTIN, Jože**, BOBOVNIK, Gregor, BAJSIČ, Ivan. Theoretical

and experimental investigations of flow pulsation effects in Coriolis mass flowmeters. Journal of sound and vibration, 2015, vol. 352, str. 30-45 [COBISS.SI-ID 14007579], [tipologija 1.01, JCR]
5. HÖGSTRÖM, Richard, HEINONEN, Martti, SPAZZINI, Pier Giorgio, KRAMER, Rainer, BUSK, Jesper, NIEDERHAUSER, Bernhard, METAXIOTOU, Zoe, BLOM, Gerard, **KUTIN, Jože**, STANKEVIČIUS, Arünas, KRAJÍČEK, Zdeněk, BARBE, Jean, ZADWORNY, Arkadiusz. EURAMET project 1325 (KCDB identifier EURAMET.M.FF-S10) : comparison for gas flow range 5 ml/min to 30 l/min : final report. [Paris: Bureau international des poids et mesures], 2021. Metrologia (Print), vol. 57, 1A. [COBISS.SI-ID 57741059], [tipologija 1.12]

Andrej Svete:

1. **SVETE, Andrej**, AMER, Eynas, JÖNSSON, Gustav, KUTIN, Jože, ARRHÉN, Fredrik. A method for correcting the high-frequency mechanical vibration effects in the dynamic calibration of pressure measurement systems using a shock tube. Mechanical systems and signal processing. Jun. 2023, vol. 193, str. 1-13. [COBISS.SI-ID 144267011], [tipologija 1.01, JCR - 1. četrtina]
2. **SVETE, Andrej**, KUTIN, Jože. Identifying the high-frequency response of a piezoelectric pressure measurement system using a shock tube primary method. Mechanical systems and signal processing. 1. jan. 2022, vol. 162, str. 1-15. [COBISS.SI-ID 63266563], [tipologija 1.01, JCR – 1. četrtina]
3. **SVETE, Andrej**, ŠTEFE, Metka, MAČEK, Andraž, KUTIN, Jože, BAJSIČ, Ivan. Dynamic pressure generator for dynamic calibrations at different average pressures based on a double-acting pneumatic actuator. Sensors and actuators. A, Physical. Aug. 2016, vol. 247, str. 136-143. [COBISS.SI-ID 14675739], [tipologija 1.01, JCR - 1. četrtina]
4. PLANKO, Urh, **SVETE, Andrej**, KUTIN, Jože. Dynamic calibration of pressure sensors with the use of different gases in the shock tube. V: IMEKO [joint] 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference, 11 – 13 October 2022, Cavtat-Dubrovnik, Croatia : IMEKO conference proceedings. [Dubrovnik]: IMECO, 2022. Str. 1-5. [COBISS.SI-ID 140263427], [tipologija 1.08]
5. **SVETE, Andrej**, KUTIN, Jože, BAJSIČ, Ivan. Calculation of response times for diaphragm seal systems. Ljubljana: Fakulteta za strojništvo, 2016. 20 f., graf. prikazi. [COBISS.SI-ID 14436379], [tipologija 2.12]