EKSPERIMENTALNO MODELIRANJE V EPS

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Eksperimentalno modeliranje v EPS
Course title:	EXPERIMENTAL MODELING IN ENERGY AND PROCESS ENGINEERING
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	**Študijska smer**	**Letnik**	**Semestri**	**Izbirnost**
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski (od študijskega leta 2024/2025 dalje)	Energetsko strojništvo (smer)	1. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566850
Koda učne enote na članici/UL Member course code:	6001-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:	Marko Hočevar, Matevž Dular

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.

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. Uvod: potek dela, obveznosti študentov, vloga predrazvoja v razvoju izdelkov, pomen eksperimentalnega modeliranja za predrazvoj strojev, naprav in procesov (a- eksperiment, b- modeliranje, c- uporaba modela). 2. Prileganje: primeri eksperimentalnega modeliranja iz energetskega in procesnega strojništva, uporaba prileganja za opis procesov in izmerjenih rezultatov, pregled primerov prileganja in pogostih funkcij prileganja, zlepki, pogoji in število pogojev. 3. Teorija podobnosti: pomen teorije podobnosti za predrazvoj strojev, naprav in procesov, tlačno, pretočno, močnostno število, specifična hitrost, diagram specifičnih hitrosti, Cordierjev diagram, primeri uporabe teorije podobnosti pri eksperimentalnem modeliranju. 4. Postopki merjenja energetskih in procesnih sistemov: pomen, opis	1. Introduction: workflow, student responsibilities, the role of pre-development in product development, the importance of experimental modeling for pre-development of machines, devices and processes (a- experiment, b- modeling, c- use of model). 2. Fitting: Examples of experimental modeling in energy and process engineering, use of fitting to describe processes and measured results, review of fitting examples and common fitting functions, splines, conditions, and the number of conditions. 3. Similarity theory: the importance of similarity theory for pre-development of machines, devices, and processes, pressure, flow rate, power number, specific velocity, specific velocity diagram, Cordier diagram, examples of the application of similarity theory in experimental modeling. 4. Procedures for measuring energy and process systems: meaning,

štirih kategorij postaj v skladu s standardi, merjene spremenljivke, način vgradnje merjenega stroja, vloga pomožnega stroja, dušilnih loput, usmerjevalnikov in umirjevalnikov toka, določanje statičnega in dinamičnega tlaka ter izgub, primeri. 5. Merilne postaje 1: merilna oprema za merjenja na merilnih postajah, izbira in vgradnja merilne opreme za pretok, tlak, in izkoristek, izvedba priključitve na merilno postajo, povezovanje v sistem. 6. Merilne postaje 2: izvedba merilnih postaj, določanje karakteristike, izkoristka in NPSH, metode za natančno merjenje navora, vrtilne frekvence in mehanske moči, izvedba uležajenja, primeri merjenja na modelu in izvedbi. 7. Pomen in način meritve električne moči: predrazvojne aktivnosti pri razvoju strojev, procesov in naprav v povezavi z električnimi lastnostmi, pomen uporabe analizatorjev moči za pogon in meritve eleketrične moči porabnikov, RMS meritev, enačbe za izračun električne moči z analizatorjem moči ali RMS merilniki toka in napetosti, fazni zamik, tokovniki in delilniki napetosti, shema priključitve merilne opreme. 8. Pomen in način meritve mehanske moči: merjenje mehanske moči na merilnih postajah: pregled različnih postopkov merjenja mehanske moči, trenje v ležajih, vgradnja merilnih lističev, tehtanje navora, primeri. 9. Spremenljivke pri eksperimentalnem modeliranju: vhodne in izhodne spremenljivke, izbira, parametri, funkcijska odvisnost, statistične metode. 10. Načrtovanje eksperimenta in predobdelava podatkov: bela, siva in črna škatla, načrtovanje eksperimenta, pametna izbira spremenljivk in njihovih vrednosti, standardni odklon in varianca, različni modeli eksperimenta,	description of four station categories following standards, measured variables, method of installation of the measured machine, role of the auxiliary machine, flow choking, flow straighteners, determination of static and dynamic pressure and losses, examples. 5. Measuring stations 1: measuring equipment for measuring at measuring stations, selection, and installation of measuring equipment for flow, pressure and efficiency, connection to the measuring station, connection to the system. 6. Measuring stations 2: design of measurement stations, determination of characteristics, efficiency and NPSH, methods for accurate measurement of torque, speed and mechanical power, bearing mounting, measurement examples on model sand prototypes. 7. Importance and method of measuring electrical power: pre-development activities in the development of machines, processes, and devices related to electrical properties, the importance of using power analyzers for propulsion and measurements of consumer electrical power, RMS measurements, equations for calculating electrical power with a power analyzer or RMS meters for current and voltage, phase delay, current and voltage dividers, wiring diagram for measuring equipment. 8. Importance and method of measuring mechanical power: Measurement of mechanical power at measuring stations: an overview of different mechanical power measurement procedures, friction in bearings, installation of measuring planes, torque weighing, examples. 9. Variables in experimental modeling: input and output variables, selection, parameters, functional dependence, statistical methods. 10. Experimental design and data pre-processing: white, gray and black

prostostne stopnje. 11. Linearni regresijski modeli: linearni regresijki modeli, polinomska regresija, interpretacija, matematične lastnosti linearnih regresijskih modelov. 12. Potenčni regresijski modeli: potenčni regresijski modeli: izbira spremenljivk, logaritmiranje. 13. Uporaba - predrazvojni primer 1: eksperimentalno modeliranje na podlagi analize slike in advekcijsko difuzijske enačbe, izbedba eksperimenta, izvedba modela. 14. Uporaba - predrazvojni primer 2: opis sušenja perila v sušilnem stroju, tokokroga zraka in hladiva, izbira spremenljivk za modeliranje časa sušenja in porabe energije, izvedba eksperimenta in linearnega regresijskega modela. 15. Uporaba - predrazvojni primer 3: razvoj eksperimentalnih modelov v povezavi s fizikalnimi modeli, pregled raziskav in rezultatov s področja kavitacije.	boxes, design of experiment, smart selection of variables and their values, standard deviation and variance, different experiment models, degrees of freedom. 11. Linear regression models: linear regression models, polynomial regression, interpretation, mathematical properties of linear regression models. 12. Potential regression models: Potential regression models: the selection of variables, logarithm. 13. Application - pre-development case 1: experimental modeling based on image analysis and advection-diffusion equation, experiment implementation, model implementation. 14. Application - pre-development case 2: description of the drying of the laundry in the dryer, the air and coolant circuits, the selection of variables for modeling the drying time and energy consumption, the execution of the experiment and a linear regression model. 15. Application - pre-development case 3: development of experimental models concerning physical models, review of research and results in the field of cavitation.

Temeljna literatura in viri/Readings:

1. Liu, A. ; Wang, Y. ; Wang, X., Data-driven engineering design, Springer, [COBISS.SI-ID 90525443], 2022.
2. H. T. Tran and H. Thomas Banks, Mathematical and Experimental Modeling of Physical and Biological Processes, Boca Raton : CRC Press, [COBISS.SI-ID 12051739], 2009.

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Spoznati princip eksperimentalnega modeliranja v energetskem in procesnem strojništvu in pomen za predrazvoj izdelkov 2. Spoznati osnovne gradnike merilnih postaj	Objectives: 1. To understand the principle of experimental modeling in energy and process engineering and the importance of the pre-development of products 2. Know the basic building blocks of

3. Razumeti pomen ustrezne izvedbe eksperimenta v energetskem in procesnem strojništvu 4. Povezati izvedbo eksperimenta z delovanjem strojev in naprav 5. Razumeti postopek eksperimentalnega modeliranja pri razvoju energetskih in procesnih strojev in naprav Kompetence: 1. S2-MAG: Sposobnost samostojne izvedbe postopka eksperimentalnega modeliranja za potrebe posamezne naloge ali aplikacije. 2. S10-MAG: Sposobnost razmevanja vpliva postopka meritev na rezultate modela. 3. P4-MAG: Sposobnost razvoja novih izdelkov na področju energetskega in procesnega strojništva. 4. P6-MAG: Sposobnost sprejemanja odločitev v energetskih in procesnih sistemih, ki se nanašajo na postopek eksperimentalnega modeliranja. 5. P7-MAG: Sposobnost diagnosticiranja posebnosti in napak delovanja energetskih strojev in procesnih naprav ter njihovo odpravljanje.	measuring stations 3. Understand the importance of performing an experiment appropriately in energy and process engineering 4. Link the performance of the experiment to the operation of machines and devices 5. Understand the process of experimental modeling in the development of energy and process machines and devices Competencies: 1. S2-MAG: Ability to perform the experimental modeling process independently for the needs of an individual task or application. 2. S10-MAG: The ability to reason the impact of the measurement process on the model results. 3. P4-MAG: Ability to develop new products in the field of energy and process engineering. 4. P6-MAG: The ability to make decisions in power and process systems related to the experimental modeling process. 5. P7-MAG: Ability to diagnose and troubleshoot energy and process machine specificities and problems.

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 eksperimentalnega modeliranja v energetskem in procesnem strojništvu. Spretnosti: S2.1: Priprava kompleksnih eksperimentov za dokazovanje delovanja energetskih strojev in procesnih sistemov. S2.2: Uporaba modernih razvojnih metod na področju energetskih strojev	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 experimental modeling in energy and process engineering. Skills: S2.1: Preparation of complex experiments to demonstrate the operation of energy machines and process systems. S2.2: Application of modern development methods in the field of

in procesnih sistemov.	energy machines and process systems.

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 energetski stroji in procesni sistemi, dušilniki, 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 postopka eksperimentalnega modeliranja P5: Uporaba študijskega gradiva kot so modeli računalniške dinamike tekočin s predstavitvijo geometrijske oblike energetskih 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 eksperimentalno modeliranje	Classical forms of teaching: P1: Lectures by solving selected - typical and practical examples. P2: Tutorials where theoretical knowledge of the lectures is supported by computational examples and explanations needed to understand the lab work P3: Laboratory exercises with dedicated didactic devices such as measuring station building blocks, various energy, and process systems, flaps, frequency converters, flow meters, temperature, relative humidity, pressure, electrical power meters, etc. Modern and flexible forms of teaching: P4: Use of study image and movie materials to demonstrate the experimental modeling process P5: Use of study materials such as models of computational fluid dynamics by presenting the geometric shape of energy machines, pressure and velocity fields, and open source software for data analysis and visualization (e.g., Paraview) P6: Literature studies and discussion P7: Group work, discussion, structured discussion during lab work and field trips P8: Virtual experiments for experimental modeling

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:

1. 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, ilustr. ISSN 0737-3937. https://www.tandfonline.com/doi/full/10.1080/07373937.2018.1502778?scroll=top&needAccess=true, DOI: 10.1080/07373937.2018.1502778. [COBISS.SI-ID 16268571]
2. PEČNIK, Boštjan, **HOČEVAR, Marko**, ŠIROK, Brane, BIZJAN, Benjamin. Scale deposit removal by means of ultrasonic cavitation. *Wear*. [Print ed.]. Jun. 2016, vol. 356/357, str. 45-52, ilustr. ISSN 0043-1648. http://www.sciencedirect.com/science/article/pii/S0043164816000843, DOI: 10.1016/j.wear.2016.03.01 [COBISS.SI-ID 14569499]
3. CENCIČ, Tine, **HOČEVAR, Marko**, ŠIROK, Brane. Study of erosive cavitation detection in pump mode of pumpstorage hydropower plant prototype. *Journal of fluids engineering* : Transactions of the ASME. May 2014, vol. 136, no. 5, str. 051301-1-051301-11, ilustr. ISSN 0098-2202. DOI: 10.1115/1.4026476. [COBISS.SI-ID 13375771]
4. KRAŠEVEC, Boris, ŠIROK, Brane, BIZJAN, Benjamin, **HOČEVAR, Marko**. Fibre density distribution in a layer of glass wool. *European journal of glass science and technology.Part A, Glass technology*. [Print ed.]. Oct. 2015, vol. 56, nr. 5, str. 145-152, ilustr. ISSN 1753-3546. DOI: 10.13036/17533546.56.5.145. [COBISS.SI-ID 14301723]
5. KRAŠEVEC, Boris, ŠIROK, Brane, **HOČEVAR, Marko**, BIZJAN, Benjamin. Multiple regression model of glass wool fibre thickness on a spinning machine. *European journal of glass science and technology.Part A, Glass technology*. [Print ed.]. Aug. 2014, vol. 55, nr. 4, str. 119-125, ilustr. ISSN 1753-3546. [COBISS.SI-ID 13639707]

Matevž Dular:

1. GOSTIŠA, Jurij, ZUPANC, Mojca, **DULAR, Matevž**, ŠIROK, Brane, LEVSTEK, Meta, BIZJAN, Benjamin. Investigation into cavitational intensity and COD reduction performance of the pinned disc reactor with various rotor-stator arrangements. *Ultrasonics Sonochemistry*. Sept. 2021, vol. 77, str. 1-11, ilustr. ISSN 1350-4177. https://www.sciencedirect.com/science/article/pii/S135041772100211X#!, DOI: 10.1016/j.ultsonch.202105669. [COBISS.SI-ID 70807811], [JCR, SNIP, WoS do 19. 2022: št. citatov (TC): 1, čistih citatov (CI): 0, čistih citatov na avtorja (CIAu): 0,00, Scopus do 2. 12. 2021: št. citatov (TC): 1, čistih citatov (CI): 0, čistih citatov na avtorja (CIAu): 0,00]
2. PODBEVŠEK, Darjan, PETKOVŠEK, Martin, OHL, Claus-Dieter, **DULAR, Matevž**. Kelvin-Helmholtz instability governs the cavitation cloud shedding in Venturi microchannel. *International journal of multiphase flow*. Sep. 2021, vol. 142, str. 1-7, ilustr. ISSN 0301-932

https://www.sciencedirect.com/science/article/pii/S0301932221001488?via%3Dihub, DOI: 10.1016/j.ijmultiphaseflow.2021.103700. [COBISS.SI-ID 66420227], [JCR, SNIP, Scopus do 29. 11. 2021: št. citatov (TC): 2, čistih citatov (CI): 0, čistih citatov na avtorja (CIAu): 0,00]

3. 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*. May/Jun. 2020, vol. 81, str. 165-172, ilustr. ISSN 0997-7546. https://www.sciencedirect.com/science/article/pii/S0997754619301463?via%3Dihub, DOI: 10.1016/j.euromechflu.2020.02.001. [COBISS.SI-ID 9085793], [JCR, SNIP, WoS do 20. 10. 2021: št. citatov (TC): 1, čistih citatov (CI): 1, čistih citatov na avtorja (CIAu): 0,17, Scopus do 24. 9. 2021: št. citatov (TC): 3, čistih citatov (CI): 3, čistih citatov na avtorja (CIAu): 0,50]
4. **DULAR, Matevž**, PETKOVŠEK, Martin. Cavitation erosion in liquid nitrogen. *Wear*. [Print ed.]. 2018, vol. 400/401, str. 111-118, ilustr. ISSN 0043-1648. https://www.sciencedirect.com/science/article/pii/S0043164817311390, DOI: 10.1016/j.wear.2018.01.003. [COBISS.SI-ID 15832859], [JCR, SNIP, WoS do 26. 12. 2021: št. citatov (TC): 10, čistih citatov (CI): 9, čistih citatov na avtorja (CIAu): 4,50, Scopus do 5. 1. 2022: št. citatov (TC): 12, čistih citatov (CI): 11, čistih citatov na avtorja (CIAu): 5,50]
5. BILUŠ, Ignacijo, BIZJAN, Benjamin, LEŠNIK, Luka, ŠIROK, Brane, PEČNIK, Boštjan, **DULAR, Matevž**. Non-contact method for analysis of cavitating flows. *Ultrasonics*. 2017, vol. 81, str. 178-186, ilustr. ISSN 0041-624X. DOI: 10.1016/j.ultras.2017.03.011. [COBISS.SI-ID 20392982], [JCR, SNIP, WoS do 9. 8. 2021: št. citatov (TC): 4, čistih citatov (CI): 2, čistih citatov na avtorja (CIAu): 0,33, Scopus do 14. 7. 2021: št. citatov (TC): 4, čistih citatov (CI): 2, čistih citatov na avtorja (CIAu): 0,33]
6. **DULAR, Matevž**. Hydrodynamic cavitation damage in water at elevated temperatures. *Wear*. [Print ed.]. Jan. 2016, vol. 346/347, str. 78-86, ilustr. ISSN 0043-1648. DOI: 10.1016/j.wear.2015.11.007. [COBISS.SI-ID 14384411], [JCR, SNIP, WoS do 5. 2. 2022: št. citatov (TC): 44, čistih citatov (CI): 41, čistih citatov na avtorja (CIAu): 41,00, Scopus do 11. 1. 2022: št. citatov (TC): 46, čistih citatov (CI): 43, čistih citatov na avtorja (CIAu): 43,00]