

MERITVE V STROJNIŠTVU

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Meritve v strojništvu
Course title:	Measurements in Mechanical Engineering
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - razvojno raziskovalni program, prva stopnja, univerzitetni	Ni členitve (študijski program)	1. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0562740
Koda učne enote na članici/UL Member course code:	2003-U

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:	doc. dr. Gregor Bobovnik, izr. prof. dr. Jože Kutin
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Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:	Obvezni splošni predmet /Compulsory general course
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Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

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

Izpolnjevanje pogojev za vpis v Univerzitetni študijski program I. stopnje Strojništvo - Razvojno raziskovalni program.

Prerequisites:

Meeting the enrollment conditions for the Academic study programme of Mechanical Engineering - Research and Development program.

Vsebina:

- 1. Temeljna izhodišča 1
- Pomen inženirskega eksperimentiranja
- Vplivni dejavniki v procesu eksperimentiranja in merjenja
- Pomen področja meroslovja
- 2. Temeljna izhodišča 2

Content (Syllabus outline):

- Fundamentals 1
- Importance of engineering experimentation
- Influence factors in experimental and measurement process
- Significance of field of metrology
- 2 Fundamentals 2

- Merilni pogrešek vs. merilna negotovost - Celovito podajanje merilnega rezultata - Pomen zagotavljanja meroslovne sledljivosti - Izhodišča procesa umerjanja oz. kalibracije - Mednarodni sistem merskih enot SI 3. Signalne značilnosti merilnega sistema - Lastnosti analognih in digitalnih merilnih signalov - Načini prenosa merilnih signalov - Vzroki za šum oz. motnje v merilnem signalu - Razumevanje parametrov, ki podajajo delež nekoristnega signala 4. Temeljni gradniki merilnih sistemov 1 - Fizikalni principi merilnih zaznaval, njihove lastnosti in omejitve - Piezoelektrični, piezouporovni, termoelektrični, uporovni, induktivni, potenciometrični, optični, ultrazvočni, Hall - Pregled in izbira merilnih zaznaval za pomembnejša merjenja v strojništvu 5. Temeljni gradniki merilnih sistemov 2 - Pregled analognih merilnih pretvornikov za pomembnejša merjenja v strojništvu - Pomen in lastnosti merilnih ojačevalnikov - Pomen in lastnosti frekvenčnih sit oz. filtrov 6. Temeljni gradniki merilnih sistemov 3 - Vloga analogno-digitalnega pretvornika (merilne kartice) - Vplivni parametri pri njihovi izbiri in uporabi, npr. frekvenca vzorčenja, število bitov - Orodja za procesiranje digitalnih merilnih signalov, virtualna instrumentacija 7. Statične lastnosti merilnih sistemov 1 - Razumevanje parametrov, ki podajajo splošne in statične lastnosti merilnih sistemov - Merilno območje, merilni razpon - Merilna značilnica, merilni model, merilna funkcija - Merilna občutljivost linearnih in nelinearnih merilnih sistemov 8. Statične lastnosti merilnih sistemov 2 - Merilna točnost, merilna natančnost - Nelinearnost, histereza, ponovljivost - Ločljivost odčitka - Zunanje vplivne veličine - Časovna stabilnost 9. Dinamske lastnosti merilnih sistemov 1 - Dinamični merilni pogrešek - Eksperimentalni pristopi k določanju dinamskih lastnosti merilnih sistemov - Dinamični generatorji merjene veličine 10. Dinamske lastnosti merilnih sistemov 2 - Razumevanje parametrov, ki podajajo lastnosti merilnega sistema pri dinamičnih merjenjih - Časovna konstanta, odzivni čas - Lastna frekvenca, dušilni razmernik - Uporabno frekvenčno območje 11. Vrednotenje merilnih rezultatov 1 - Metodologija vrednotenja kakovosti merilnih rezultatov	- Measurement error vs measurement uncertainty - Complete statement of measurement result - Importance of assuring a metrological traceability - Fundamentals about calibration process - International system of units (SI) 3 Signal characteristics of measuring systems - Characteristics of analog and digital measurement signals - Methods of transmission of measurement signals - Causes for noise and disturbances in measurement signals - Understanding the parameters that express share of unwanted signal 4 Components of measuring systems 1 - Physical principles of sensors, their characteristics and limitations - Piezoelectric, piezoresistive, thermoelectric, resistive, inductive, potentiometric, optical, ultrasonic, Hall - Review and selection of sensors for most important measurements in mechanical engineering 5 Components of measuring systems 2 - Review of analog measuring transmitters for most important measurements in mechanical engineering - Applications and characteristics of measuring amplifiers - Applications and characteristics of frequency filters 6 Components of measuring systems 3 - Role of analog-digital converter (data acquisition device) - Influential parameters on their selection and application, eg., sampling frequency, number of bits. - Tools for processing digital measurement signals, virtual instrumentation 7 Static characteristics of measuring systems 1 - Understanding the parameters that define general and static characteristics of measuring systems - Measuring range, measuring span - Measuring characteristic, measurement model, measurement function - Measurement sensitivity of linear and nonlinear measuring systems 8 Static characteristics of measuring systems 2 - Measurement accuracy, precision - Nonlinearity, hysteresis, repeatability - Resolution - External influential quantities - Time stability 9 Dynamic characteristics of measuring systems 1 - Dynamic measurement error - Experimental determination of dynamic
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- Prepoznavanje potencialnih vplivov - Ocena vplivov, ki so povezani z lastnostmi in načinom uporabe merilnega sistema 12. Vrednotenje merilnih rezultatov 2 - Statistično vrednotenje merilnih rezultatov - Ocena srednje vrednosti - Ocena raztrosa izmerkov, raztrosa srednje vrednosti - Vpliv končnega števila izmerkov na oceno intervala zaupanja, faktorja pokritja 13. Vrednotenje merilnih rezultatov 3 - Ocena skupne standardne in razširjene merilne negotovosti - Vrednotenje rezultatov neposrednih merenj - Vrednotenje rezultatov posrednih merenj - Vrednotenje rezultatov primerjalnih merenj 14. Obvladovanje merilnega sistema in procesa merjenja – izbrani primeri 1 - Celoviteje predstavljeni izbrani primeri merenj v strojništvu: npr. merjenje deformacij, sil, navora itd. z uporovnimi merilnimi lističi - Konfiguracija merilnega sistema - Vplivne veličine na kakovost merjenja 15. Obvladovanje merilnega sistema in procesa merjenja – izbrani primeri 2 - Celoviteje predstavljeni izbrani primeri merenj v strojništvu: npr. merjenje mehanskih nihanj, tlakov itd. s piezoelektričnimi merilnimi zaznavali - Konfiguracija merilnega sistema - Vplivne veličine na kakovost merjenja - Drugi možni primeri: merjenja z induktivnimi, kapacitivnimi, optičnimi merilnimi sistemi	characteristics of measuring systems - Dynamic generators of measured quantity 10 Dynamic characteristics of measuring systems 2 - Understanding the parameters that define characteristics of measuring systems in dynamic measurements - Time constant, response time - Natural frequency, damping ratio - Useful frequency range 11 Evaluation of measurement results 1 - Methodology for evaluation of quality of measurement results - Recognizing potential influences - Estimation of influences related to characteristics of measuring system and the way of its usage 12 Evaluation of measurement results 2 - Statistical evaluation of measurement results - Estimating the mean value - Estimating the scatter of measured values, scatter of the mean value - Effect of finite number of measurements on confidence interval, coverage factor 13 Evaluation of measurement results 3 - Estimation of combined standard and expanded measurement uncertainty - Evaluation of results of direct measurements - Evaluation of results of indirect measurements - Evaluation of results of comparison measurements 14 Management of measuring system and measurement process – case study 1 - Detailed study of selected cases of measurements in mechanical engineering: eg., measurements of deformation, force, torque, etc., using strain gauges - Configuration of measuring system - Influences on quality of measurement 1. Management of measuring system and measurement process – case study 2 - Detailed study of selected cases of measurements in mechanical engineering: e.g., measurements of vibration, pressure, etc., using piezoelectric sensors - Configuration of measuring system - Influences on quality of measurement - Other potential cases: measurements using inductive, capacitive, optical measuring systems
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Temeljna literatura in viri/Readings:

1. Kirkup, L., Frenkel, R. B.: An introduction to uncertainty in measurement using the GUM. Cambridge University Press, 2006. [COBISS.SI-ID [666619](#)]
2. Slaev, V. A., Chunovkina, A. G., Mironovsky, L. A.: Metrology and theory of measurement. De Gruyter, 2013. [COBISS.SI-ID [13148955](#)]
3. Figliola, R. S., Beasley, D. E.: Theory and design for mechanical measurements. Wiley, 2011. [COBISS.SI-ID [35307013](#)]

4. Morris, A. S.: Measurement & instrumentation principles. Butterworth-Heinemann, 200 [COBISS.SI-ID 2266708] 5. Hashemian, H. M.: Sensor performance and reliability. ISA, 2005. [COBISS.SI-ID 10583323] 6. Montgomery, D. C., Runger, G. C.: Applied statistics and probability for engineers. Wiley, 2014. [COBISS.SI-ID 16830747]
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Cilji in kompetence:	Objectives and competences:
Cilji: 1. Spoznati pomen eksperimentalnega dela in merjenja 2. Spoznati temeljne gradnike in izhodišča načrtovanja merilnih sistemov s področja merjenje v strojništvu 3. Razumeti ključne parametre za popis statičnih in dinamičnih lastnosti merilne opreme in merilnih sistemov 4. Spoznati vplivne dejavnike v procesu merjenja in metodologijo vrednotenja merilnih rezultatov Kompetence: 1. S4-RRP: Sposobnost strokovnega sporazumevanja in pisnega izražanja na področju eksperimentiranja in meroslovja. 2. P1-RRP: Obvladovanje temeljnih znanj glede popisa lastnosti merilne opreme in merilnih sistemov, izvajanja meritev in vrednotenja merilnih rezultatov. 3. S6-RRP + P6-RRP: Sposobnost uporabe pridobljenih znanj pri načrtovanju merilnih sistemov, izvajanju meritev in vrednotenju merilnih rezultatov.	Objectives: 1. To familiarize with the importance of experimental work and measurements 2. To familiarize with components and design of measuring systems in the field of measurements in mechanical engineering 3. To understand key parameters for description of static and dynamic characteristics of measuring instruments and measuring systems 4. To familiarize with influence parameters in measurement process and methodology for evaluation of measurement results Competences: 1. S4-RRP: Professional communication and writing communication skills, including the use of foreign technical language in field of metrology. 2. P1-RRP: Mastery of basic theoretic skills related to the description of measuring instruments and measuring systems, performing measurements and evaluation of measurement results. 3. S6-RRP + P6-RRP: The ability to use the acquired knowledge for designing of measuring systems, performing measurements and evaluation of measurement results

Predvideni študijski rezultati:	Intended learning outcomes:
Znanja: Z1: Poglobljeno strokovno teoretično in praktično znanje na določenem področju, podprto s širšo teoretično in metodološko osnovo. - Znanje o procesu eksperimentiranja in merjenja, s poudarkom na metodologiji izbire merilne opreme, načrtovanju merilnih sistemov ter obvladovanju kakovosti merjenj in vrednotenja merilnih rezultatov. Spretnosti: S1.1 Izvajanje kompleksnih operativno-strokovnih opravil, ki vključujejo tudi uporabo metodoloških orodij. - Načrtovanje merilnih sistemov želene merilne točnosti, dinamičnih lastnosti itd. S1.2 Obvladovanje zahtevnih, kompleksnih delovnih procesov ob samostojni uporabi znanja v novih delovnih situacijah. - Obvladovanje izbire merilne opreme in vplivov na proces merjenja. S1.3 Diagnosticiranje in reševanje problemov v različnih specifičnih delovnih okoljih, povezanih s področjem izobraževanja in usposabljanja. - Reševanje problemov s področja vrednotenja merilnih rezultatov.	Outcomes: Z1: Thorough professional theoretical and practical knowledge in a selected field of expertise that is supported with a broad theoretical and methodological basis. - Knowledge about experimental and measurement processes with emphasis on methodology of selection of measuring instruments, design of measuring systems, management of measurement quality and evaluation of measurements results. Skills: S1.1 Executing complex operationa-professional tasks that incorporate usage of methodological tools. - Design of measuring systems with target measurement accuracy, dynamic characteristics, etc. S1.2 Mastering demanding and complex work processes by independent usage of knowledge in new working situations. - Management of selection of measuring instruments, management of influences on measurement process. S1.3 Problem diagnostics and solving in different and specific working environments that are linked to the teaching and training content.

	- Solving problems related to evaluation of measurement results.
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Metode poučevanja in učenja:

P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov.
P4 Laboratorijske vaje z namenski didaktičnimi pripomočki (merilni sistemi s področja merjenj v strojništvu, računalniško nadzorovani merilni sistemi, merilni sistemi za statična in dinamična merjenja).
P6 Interaktivna predavanja
P9 Skupinsko delo
P14 Virtualni eksperimenti
P15 Uporaba video vsebin kot priprava na predavanja in vaje

Learning and teaching methods:

P1 Auditorial lectures with solving selected field-specific theoretical and applied use cases.
P4 Laboratory exercises with special-purpose didactic devices (measuring systems applicable in mechanical engineering, computer controlled measuring systems, measuring systems for static and dynamic measurements).
P6 Interactive lectures.
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 %	Theoretical part (lectures)
Praktični del (računske in laboratorijske vaje)	50,00 %	Practical part (calculation and laboratory exercises)
Ustni zagovor predloga ocene		Oral examination of the proposed grade

Ocenjevalna lestvica:

5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10

Grading system:

5 - 10, a student passes the exam if he is graded from 6 to 10

Reference nosilca/Lecturer's references:

Jože Kutin:

- SVETE, Andrej, HERNÁNDEZ CASTRO, Francisco Javier, **KUTIN, Jože**. Effect of the dynamic response of a side-wall pressure measurement system on determining the pressure step signal in a shock tube using a time-of-flight method. *Sensors*. Mar. 2022, vol. 22, iss. 6, str. 1-15 [COBISS.SI-ID [100476931](#)].
- ŽIBRET, Primož, BOBOVNIK, Gregor, **KUTIN, Jože**. Time-correction model based on diverter speed for a pVTt gas flow primary standard. *Sensors*. May 2022, vol. 22, iss. 11, str. 1-12 [COBISS.SI-ID [109539075](#)].
- ŠTEFE, Metka, SVETE, Andrej, **KUTIN, Jože**. Development of a dynamic pressure generator based on a loudspeaker with improved frequency characteristics. *Measurement*, Jul. 2018, vol. 122, str. 212-219 [COBISS.SI-ID [15951643](#)].
- HERNÁNDEZ CASTRO, Francisco Javier, **KUTIN, Jože**, SVETE, Andrej. Effects of the opening speed of the valve in a diaphragmless shock tube for metrological purposes. *IEEE sensors journal*. [Print ed.]. Jan. 2024, vol. 24, no. 1, str. 158-168. [COBISS.SI-ID [179395587](#)].
- KUTIN, Jože**, BOBOVNIK, Gregor, GUGOLE, Federica, VEEN, Adriaan M.H. van der. Evaluation of uncertainty associated with totalisation of time-sampled data in gas quantity and energy measurements. *Measurement. Sensors*. 2025, vol. , no. , [article no.] 101572, 4 str. [COBISS.SI-ID [234750979](#)].

Gregor Bobovnik:

- BOBOVNIK, Gregor**, KUTIN, Jože. Uncertainty analysis of the air velocity standard based on LDA and wind tunnel. *Measurement*. Jan. 2023, vol. 206, str. 1-9. [COBISS.SI-ID [136179203](#)].
- BOBOVNIK, Gregor**, MUŠIČ, Tim, KUTIN, Jože. Liquid level detection in standard capacity measures with machine vision. *Sensors*. Apr. 2021, vol. 21, iss. 8, str. 1-13. [COBISS.SI-ID [59221251](#)].
- BÖCKLER, H.-B., DE HUU, M., MAURY, Rémy, SCHMELTER, S., SCHAKEL, Menne D., BÜKER, Oliver, KUTIN, Jože, **BOBOVNIK, Gregor**, WEDLER, C., TRUSLER, J. P. M., THOL, M., WEISS, S., GÜNZ, C., SCHUMANN, D., GUGOLE, F. Metrology infrastructure for high-pressure gas and liquified hydrogen flows : a brief outline of the MetHyInfra project, measurement challenges, and first results. *Measurement*. Jun. 2024, vol. 232, [article no.] 114675, str. 1-12. [COBISS.SI-ID [192327939](#)].

4. **BOBOVNIK, Gregor**, ARHAR, Klara, KUTIN, Jože. Validacija merilnega sistema za merjenje pretoka plina z laminarnim tokovnim elementom. Ventil : revija za fluidno tehniko in avtomatizacijo. feb. 2020, letn. 26, št. 1, str. 32-37, ilustr. ISSN 1318-7279. [COBISS.SI-ID [17062683](#)].
5. **BOBOVNIK, Gregor**, SAMBOL, Peter, GERŠL, Jan, KUTIN, Jože. Experimental study of the blockage effect of a vane anemometer in a small wind tunnel. Measurement. Sensors. 2025, vol. , no. , [article no.] 101561, 5 str. [COBISS.SI-ID [234738179](#)].