NAPREDNI ODREZOVALNI PROCESI

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Napredni odrezovalni procesi
Course title:	Advanced Machining Processes
Članica nosilka/UL Member:	UL FS

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

Univerzitetna koda predmeta/University course code:	0566830
Koda učne enote na članici/UL Member course code:	6045-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:	izr. prof. dr. Davorin Kramar, prof. dr. Franci Pušavec

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

Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Proizvodno strojništvo, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Production 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. Osnovna kinematika orodja in tvorjenje odrezka	1. Basic tool kinematics and chip formation
- Sistem stroj-orodje-obdelovanec	- Machine-tool-workpiece system
- Kinematika odrezovalnih procesov	- Kinematics of machining processes
- Rezalna geometrija in terminologija	- Cutting geometry and terminology
2. Definirana rezalna geometrija	2. Defined cutting geometry
- Procesi z definirano rezalno geometrijo	- Processes with defined cutting geometry
- Tvorba odrezka	- Chip formation
- Rezalni parametri	- Cutting parameters
3. Modeli tvorbe odrezkov	3. Chip formation models
- Mehanika ortogonalnega reza	- Mechanics of orthogonal cutting model
- Mehanika poševnega reza	- Oblique cut mechanics
- Umestitev modelov na realne odrezovalne procese	- Placement of models on real machining processes
4. Določanje odrezovalne učinkovitosti	4. Determination of machining efficiency
- Obdelovalnost materialov	- Machining performanc of materials
- Obdelovalne strategije in kriteriji	- Machining strtegies and criteria
- Produktivnost	- Productivity
5. Rezalne sile	5. Cutting forces
- Sile pri odrezavanju	- Forces in cutting process
- Modeli napovedovanja sil	- Force prediction models
- Vpliv rezalnih sil na proces in njegovo stabilnost	- Influence of cutting forces on the process and its stability
6. Nedefinirane rezalne geometrije	6. Nondefined cutting geometry
- Procesi z nedefinirano rezalno geometrijo	- Processes with undefined cutting geometry
- Popis kinematike spektra takih procesov	- An overview of the kinematics spectrum of such processes
- Problematike procesov	- Process issues
7. Toplotne obremenitve pri odrezavanju	7. Thermal loads in machining
- Toplotne razmere pri odrezavanju	- Thermal conditions in cutting
- Vpliv na proces	- Influence on process
- Vpliv na integriteto obdelane površine	- Influence on the machined surface integrity
8. Obraba in obstojnost	8. Tool-wear and tool-life
- Obraba rezalnih orodij	- Wear of cutting tools
- Obrabni mehanizmi	- Wear mechanisms
- Modeliranje obstojnosti rezalnih orodij	- Modeling of cutting tool-life
9. Rezalna orodja	9. Cutting tools
- Rezalni materiali	- Cutting tool materials
- Vpliv rezalnih materialov na proces odrezavanja	- Impact of cutting materials on the cutting process
- Smernice njihove uporabe	- Guidelines for their use
10. Zaščite rezalnih orodij	10. Cutting tool coatings
- Prevleke rezalnih orodij	- Coatings of cutting tools
- Funkcionalne lastnosti prevlek	- Functional properties of coatings
- Vpliv prevlek na rezalno geometrijo in proces	- Influence of coatings on cutting geometry and process
11. Mazanje in hlajenje odrezovalnih procesov	11. Cooling and lubrication of machining processes
- Hladilno mazalna sredstva	- Coolant and/or lubricants
- Hladilno mazalni principi	- Cooling lubrication principles
- Smernice	- Guidelines
12. Produktivnost in ekonomičnost	12. Productivity and economy
- Načrtovanje tehnoloških parametrov	- Design of technological parameters
- Omejitve pri določevanju parametrov	- Constraints on parameter determination
- Ekonomsko vrednotenje	- Economic evaluation
13. Optimiranje odrezovalnih procesov	13. Optimization of machining processes
- Visoko produktivno odrezavanje	- Higher performance machining
- Visoko hitrostno odrezavanje	- High speed machining
- Optimiranje odrezovalnih procesov	- Optimization of machining processes
14. Posebni odrezovalni procesi	14. Special/modern machining processes
- Hibridni postopki odrezavanja	- Hybrid machining processes
- Trajnostni elementi/smernice	- Sustainable elements / guidelines
- Mikro odrezavanje	
15. Gostujoče predavanje z industrije	
- Gostujoče predavanje eksperta s postavljanja	

odrezovalnih tehnologij v industrijskih aplikacijah (BTS Company)	- Micro machining 15. Guest lecture by an expert from industry on machining technologies in industrial applications (BTS Company).

Temeljna literatura in viri/Readings:

1. Energy efficient manufacturing: theory and applications. Hoboken (NJ); Beverly (MA): Wiley; Scrivener Publishing, 2018, str. XIV, 45 ISBN 978-1-118-42384-4, [COBISS.SI-ID 158647811]
2. Modern manufacturing processes. Hoboken (NJ): Wiley, 2020, str. XXI, 514. ISBN 978-1-118-07192-2, [COBISS.SI-ID 149649411]
3. M. P. Groover, Fundamentals of modern manufacturing: materials, processes, and systems, 7th ed. Hoboken (NJ): John Wiley & Sons, 2020, str. XIV, 703, 71, 14. ISBN 978-1-119-72201-4, [COBISS.SI-ID 146641667]
4. G. Globočki-Lakić, D. Kramar, in J. Kopač, Metal cutting: theory and applications. Banja Luka; Ljubljana: Faculty of Mechanical Engineering; Faculty of Mechanical Engineering, 2014, str. XIII, 221. ISBN 978-99938-39-49-1, [COBISS.SI-ID 277173760]
5. J. Kopač, Odrezavanje: teoretične osnove in tehnološki napotki. Ljubljana [i. e.] Domžale: [samozal.] J. Kopač, 2008, str. 264. ISBN 978-961-245-583-5, [COBISS.SI-ID 241209856]
6. F. Pušavec in J. Kopač, Trajnostni razvoj obdelovalnih procesov = Sustainable development of manufacturing processes. Ljubljana: Fakulteta za strojništvo, 2010, str. 1 zv. [COBISS.SI-ID 11388187]

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Pridobiti poglobljena znanje o odrezovalnih procesih. 2. Seznanitev z naprednimi in inovativnimi odrezovalnimi procesi in tehnologijami. 3. Poznavanje postavljanja tehnologij, izračunov časov obdelav, obremenitev orodij, ter obstojnosti za optimalno delovanje procesov. 4. Poznavanje modelov za popisovanje in napovedovanje odrezovalnih procesov Kompetence: 1. S1-MAG: Temeljna usposobljenost in razumevanje področja odrezovalnih procesov, ki omogoča reševanje znanstvenih problemov in strokovnih izzivov. 2. S7-MAG: Sposobnost uporabe sodobnih odrezovalnih procesov in njihovih raziskovalnih metod. Zmožnost njihovega optimiranja in prenašanja temeljnjih znanj in spoznanj v prakso. 3. P3-MAG: Obvladovanje temeljnih teoretičnih in aplikativnih znanj s širokega področja odrezovalnih procesov, ki so bistvena za obvladovanje področja proizvodnih tehnologij.	Objectives: 1. To acquire in-depth knowledge of machining processes. 2. Familiarity with advanced and innovative machining processes and technologies. 3. Knowledge on technology development, cycle time calculations, tool loads, and tool-life for optimal process performance. 4. Knowledge of models for enumerating and predicting behaviour of machining processes Competences: 1. S1-MAG: Basic competence and understanding of the field of machining processes, which enables solving scientific problems and professional challenges. 2. S7-MAG: Ability to use modern machining processes and their research methods. Ability to optimize them and bring them into practice. 3. P3-MAG: Mastering the fundamental theoretical and applied knowledge of a wide range of machining processes that is essential to mastering manufacturing technology.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja:	Knowledge:

Z2: Poglobljeno teoretično, metodološko in analitično znanje s področja principov odrezovalnih procesov in tvorbe odrezkov, ki je osnova za zahtevno aplikativno delo. Spretnosti: S2.1 Poznavanje in obvladovanje zahtevnih / kompleksnih odrezovalnih procesov, in metodoloških orodij za modeliranje/napovedovanje obnašanja. S2.2 Načrtovanje tehnologij odrezavanja na podlagi reševanja problemov. S2.3 Sposobnost kritične refleksije in inovativnega nadgrajevanja.	Z2: In-depth theoretical, methodological and analytical knowledge of the principles of machining processes and chip formation, which is the basis for demanding application work. Skills: S2.1 Knowledge and management of demanding / complex machining processes, and methodological tools for modeling / predicting behavior. S2.2 Designing machining technologies based on problem solving. S2.3 Ability to reflect critically and innovate upgrades.

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 v laboratoriju na obdelovalnih strojih P6 Interaktivna predavanja P8 Izdelava in predstavitev aplikativnih seminarskih nalog P15 Uporaba video vsebin kot priprava na predavanje in vaje.	P1 Lectures by solving selected - typical - theoretical and practical examples. P3 Practical classes where theoretical knowledge from lectures is supported by computational examples P4 Laboratory exercises in the laboratory on machine tools P6 Interactive Lectures P8 Design and presentation of applied seminar work P15 Use video content to prepare for lectures and tutorials.

Načini ocenjevanja:	**Delež/Weight**	**Assessment:**
- Teoretične vsebine (predavanja)	50,00 %	- Theoretical content (lectures)
- Delo na laboratorijskih vajah (vključno s poročili)	50,00 %	- Laboratory work (including reports)

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:

Franci Pušavec:

1. KERN, Matjaž, DRAŽUMERIČ, Radovan, **PUŠAVEC, Franci**. Analytical study on critical load and deformation of chip in high-pressure jet assisted machining. Journal of materials processing technology. Jul. 2023, vol. 316, str. 1-12, ilustr. ISSN 0924-0136. https://www.sciencedirect.com/science/article/pii/S0924013623000894, https://repozitorij.uni-

lj.si/IzpisGradiva.php?id=147996, DOI: 10.1016/j.jmatprotec.2023.117944. [COBISS.SI-ID 158995971]

2. RODRIGUEZ, Iñigo, ARRAZOLA, Pedro J., CUESTA, Mikel, STERLE, Luka, **PUŠAVEC, Franci**. Improving surface integrity when drilling CFRPs and Ti-6Al-4V using sustainable lubricated liquid carbon dioxide. Chinese journal of aeronautics. July 2023, vol. 36, iss. 7, str. 129-146, ilustr. ISSN 1000-936 https://www.sciencedirect.com/science/article/pii/S1000936122001960, DOI: 10.1016/j.cja.2022.09.004. [COBISS.SI-ID 135011843]
3. TEŠIĆ, Saša, CICA, Djordje, BOROJEVIĆ, Stevo, SREDANOVIĆ, Branislav, ZELJKOVIĆ, Milan, KRAMAR, Davorin, **PUŠAVEC, Franci**. Optimization and prediction of specific energy consumption in ball-end milling of Ti-6Al-4V alloy under mql and cryogenic cooling/lubrication conditions. International journal of precision engineering and manufacturing. Green engineering. Nov. 2022, iss. 9, str. 1427–1437, ilustr. ISSN 2198-0810. https://link.springer.com/article/10.1007/s40684-021-00413-9, DOI: 10.1007/s40684-021-00413-9. [COBISS.SI-ID 110628867]
4. RODRIGUEZ, I., SORIANO, D., ORTIZ-DE-ZARATE, G., CUESTA, M., **PUŠAVEC, Franci**, ARRAZOLA, P. J. Effect of tool geometry and LCO2 cooling on cutting forces and delamination when drilling CFRP composites using PCD tools. V: RECH, Joël (ur.), OUTEIRO, J.C. (ur.). 6th CIRP Conference on Surface Integrity, 8th - 10th June 2022, Lyon, France. 6th CIRP Conference on Surface Integrity, 8th - 10th June 2022, Lyon, France. [S. l.]: Elsevier, 2022. Vol. 108, str. 752-757, ilustr. Procedia CIRP, Vol. 108. ISSN 2212-8271. https://www.sciencedirect.com/science/article/pii/S2212827122006084, DOI: 10.1016/j.procir.2022.0116. [COBISS.SI-ID 113755139]
5. KENDA, Jani, **PUŠAVEC, Franci**, KOPAČ, Janez. Arrangements and methods for abrasive flow machining = Anordnungen und Verfahren zur Schleifmittelstormesbearbeitung = Agencements et procédés d'usinage par écoulement abrasif : European patent specification EP 2996840 B1, 2021-10-06. Munich: European Patent Office, 2021. 14 f., ilustr. https://worldwide.espacenet.com/patent/search/family/050687475/publication/EP2996840B1?q=pn%3DEP2996840A1. [COBISS.SI-ID 13043995]

Davorin Kramar:

1. CICA, Djordje, **KRAMAR, Davorin**. Machinability investigation and sustainability analysis of high-pressure coolant assisted turning of the nickel-based superalloy Inconel 718. Proceedings of the Institution of Mechanical Engineers. Part B, Journal of engineering manufacture, ISSN 0954-4054, 2023, vol. 237, iss. 1/2, str. 43%54, ilustr. https://journals.sagepub.com/doi/10.1177/09544054221092939, doi: 10.1177/09544054221092939. [COBISS.SI-ID 110610691]
2. TEŠIĆ, Saša, CICA, Djordje, BOROJEVIĆ, Stevo, SREDANOVIĆ, Branislav, ZELJKOVIĆ, Milan, **KRAMAR, Davorin**, PUŠAVEC, Franci. Optimization and prediction of specific energy consumption in ball-end milling of Ti-6Al-4V alloy under mql and cryogenic cooling/lubrication conditions. International journal of precision engineering and manufacturing, Green engineering, ISSN 2198-0810, Nov. 2022, iss. 9, str. 1427%1437, ilustr. https://link.springer.com/article/10.1007/s40684-021-00413-9, doi: 10.1007/s40684-021-00413-9. [COBISS.SI-ID 110628867]
3. CICA, Djordje, SREDANOVIĆ, Branislav, TEŠIĆ, Saša, **KRAMAR, Davorin**. Predictive modeling of turning operations under different cooling/lubricating conditions for sustainable manufacturing with machine learning techniques. *Applied computing and informatics*. 2024, vol. 20, no. 1/2, str. 162-180, ilustr. ISSN 2210-8327. https://www.emerald.com/insight/content/doi/10.1016/j.aci.2020.02.001/full/html, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.aci.2020.02.001. [COBISS.SI-ID 66118659]
4. RODIĆ, Dragan, SEKULIĆ, Milenko, GOSTIMIROVIĆ, Marin, PUCOVSKY, Vladimir, **KRAMAR, Davorin.** Fuzzy logic and sub-clustering approaches to predict main cutting force in high-pressure jet assisted turning. Journal of intelligent manufacturing, ISSN 0956-5515, Jan. 2021, vol. 32, iss. 1, str. 21-36, ilustr. https://link.springer.com/article/10.1007/s10845-020-01555-4, doi: 10.1007/s10845-020-01555-4. [COBISS.SI-ID 17169691]

5. CICA, Djordje, **KRAMAR, Davorin**. Multi-objective optimization of high-pressure jet-assisted turning of Inconel 718. International journal of advanced manufacturing technology, ISSN 0268-3768, 2019, vol. 105, str. 4731-4745, ilustr. https://link.springer.com/article/10.1007%2Fs00170-019-04513-4, doi: 10.1007/s00170-019-04513-4. [COBISS.SI-ID 16992027]