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 (od študijskega leta 2024/2025 dalje)	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:	Davorin Kramar, 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 - Sistem stroj-orodje-obdelovanec - Kinematika odrezovalnih procesov - Rezalna geometrija in terminologija 2. Definirana rezalna geometrija - Procesi z definirano rezalno geometrijo - Tvorba odrezka - Rezalni parametri 3. Modeli tvorbe odrezkov - Mehanika ortogonalnega reza - Mehanika poševnega reza - Umestitev modelov na realne odrezovalne procese 4. Določanje odrezovalne učinkovitosti - Obdelovalnost materialov - Obdelovalne strategije in kriteriji - Produktivnost 5. Rezalne sile - Sile pri odrezavanju - Modeli napovedovanja sil - Vpliv rezalnih sil na proces in njegovo stabilnost 6. Nedefinirane rezalne geometrije - Procesi z nedefinirano rezalno	1. Basic tool kinematics and chip formation - Machine-tool-workpiece system - Kinematics of machining processes - Cutting geometry and terminology 2. Defined cutting geometry - Processes with defined cutting geometry - Chip formation - Cutting parameters 3. Chip formation models - Mechanics of orthogonal cutting model - Oblique cut mechanics - Placement of models on real machining processes 4. Determination of machining efficiency - Machining performanc of materials - Machining strtegies and criteria - Productivity 5. Cutting forces - Forces in cutting process - Force prediction models - Influence of cutting forces on the process and its stability

geometrijo - Popis kinematike spektra takih procesov - Problematike procesov 7. Toplotne obremenitve pri odrezavanju - Toplotne razmere pri odrezavanju - Vpliv na proces - Vpliv na integriteto obdelane površine 8. Obraba in obstojnost - Obraba rezalnih orodij - Obrabni mehanizmi - Modeliranje obstojnosti rezalnih orodij 9. Rezalna orodja - Rezalni materiali - Vpliv rezalnih materialov na proces odrezavanja - Smernice njihove uporabe 10. Zaščite rezalnih orodij - Prevleke rezalnih orodij - Funkcionalne lastnosti prevlek - Vpliv prevlek na rezalno geometrijo in proces 11. Mazanje in hlajenje odrezovalnih procesov - Hladilno mazalna sredstva - Hladilno mazalni principi - Smernice 12. Produktivnost in ekonomičnost - Načrtovanje tehnoloških parametrov - Omejitve pri določevanju parametrov - Ekonomsko vrednotenje 13. Optimiranje odrezovalnih procesov - Visoko produktivno odrezavanje - Visoko hitrostno odrezavanje - Optimiranje odrezovalnih procesov 14. Posebni odrezovalni procesi - Hibridni postopki odrezavanja - Trajnostni elementi/smernice - Mikro odrezavanje 15. Gostujoče predavanje z industrije - Gostujoče predavanje eksperta s postavljanja odrezovalnih tehnologij v industrijskih aplikacijah (BTS Company)	6. Nondefined cutting geometry - Processes with undefined cutting geometry - An overview of the kinematics spectrum of such processes - Process issues 7. Thermal loads in machining - Thermal conditions in cutting - Influence on process - Influence on the machined surface integrity 8. Tool-wear and tool-life - Wear of cutting tools - Wear mechanisms - Modeling of cutting tool-life 9. Cutting tools - Cutting tool materials - Impact of cutting materials on the cutting process - Guidelines for their use 10. Cutting tool coatings - Coatings of cutting tools - Functional properties of coatings - Influence of coatings on cutting geometry and process 11. Cooling and lubrication of machining processes - Coolant and/or lubricants - Cooling lubrication principles - Guidelines 12. Productivity and economy - Design of technological parameters - Constraints on parameter determination - Economic evaluation 13. Optimization of machining processes - Higher performance machining - High speed machining - Optimization of machining processes 14. Special/modern machining processes - Hybrid machining processes - Sustainable elements / guidelines - 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:

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

Objectives and competences:

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

procesov, ki so bistvena za obvladovanje področja proizvodnih tehnologij.	of machining processes that is essential to mastering manufacturing technology.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: 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.	Knowledge: 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], [JCR, SNIP, WoS do 7. 6. 2022: št. citatov (TC): 0, čistih citatov (CI): 0, Scopus do 7. 6. 2022: št. citatov (TC): 0, čistih citatov (CI): 0]
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], [JCR, SNIP, WoS do 7. 6. 2022: št. citatov (TC): 0, čistih citatov (CI): 0, Scopus do 7. 6. 2022: št. citatov (TC): 0, čistih citatov (CI): 0]
3. MUŽENIČ, David, **KRAMAR, Davorin**, PUŠAVEC, Franci. Advances in understanding of damage formation during laser-assisted milling of ZnO-based varistor ceramics. *Journal of manufacturing processes*, ISSN 1526-6125. [Print ed.], Dec. 2022, vol. 84, str. 1478-1491, ilustr. https://www.sciencedirect.com/science/article/pii/S1526612522007812, doi: 10.1016/j.jmapro.2022.11.008. [COBISS.SI-ID 130224387], [JCR, SNIP, WoS do 22. 1. 2023: št. citatov (TC): 0, čistih citatov (CI): 0, Scopus do 10. 12. 2022: št. citatov (TC): 0, čistih citatov (CI): 0]
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], [JCR, SNIP, WoS do 22. 2023: št. citatov (TC): 9, čistih citatov (CI): 9, Scopus do 1 1. 2023: št. citatov (TC): 8, čistih citatov (CI): 8]
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], [JCR, SNIP, WoS do 26. 10. 2022: št. citatov (TC): 10, čistih citatov (CI): 9, Scopus do 14. 2. 2023: št. citatov (TC): 13, čistih citatov (CI): 12]