

# NAPREDNI ODREZOVALNI PROCESI

## UČNI NAČRT PREDMETA/COURSE SYLLABUS

<b>Predmet:</b>	Napredni odrezovalni procesi
<b>Course title:</b>	Advanced machining processes
<b>Članica nosilka/UL Member:</b>	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

<b>Univerzitetna koda predmeta/University course code:</b>	0566830
<b>Koda učne enote na članici/UL Member course code:</b>	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

<b>Nosilec predmeta/Lecturer:</b>	Davorin Kramar, Franci Pušavec
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<b>Izvajalci predavanj:</b>	
<b>Izvajalci seminarjev:</b>	
<b>Izvajalci vaj:</b>	
<b>Izvajalci kliničnih vaj:</b>	
<b>Izvajalci drugih oblik:</b>	
<b>Izvajalci praktičnega usposabljanja:</b>	

**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 performance of materials
  - Machining strategies and criteria
  - Productivity
5. Cutting forces
  - Forces in cutting process
  - Force prediction models
  - Influence of cutting forces on the process and its stability

<p>geometrijo</p> <ul style="list-style-type: none"> <li>- Popis kinematike spektra takih procesov</li> <li>- Problematike procesov</li> </ul> <p>7. Toplotne obremenitve pri odrezavanju</p> <ul style="list-style-type: none"> <li>- Toplotne razmere pri odrezavanju</li> <li>- Vpliv na proces</li> <li>- Vpliv na integriteto obdelane površine</li> </ul> <p>8. Obraba in obstojnost</p> <ul style="list-style-type: none"> <li>- Obraba rezalnih orodij</li> <li>- Obrabni mehanizmi</li> <li>- Modeliranje obstojnosti rezalnih orodij</li> </ul> <p>9. Rezalna orodja</p> <ul style="list-style-type: none"> <li>- Rezalni materiali</li> <li>- Vpliv rezalnih materialov na proces odrezavanja</li> <li>- Smernice njihove uporabe</li> </ul> <p>10. Zaščite rezalnih orodij</p> <ul style="list-style-type: none"> <li>- Prevleke rezalnih orodij</li> <li>- Funkcionalne lastnosti prevlek</li> <li>- Vpliv prevlek na rezalno geometrijo in proces</li> </ul> <p>11. Mazanje in hlajenje odrezovalnih procesov</p> <ul style="list-style-type: none"> <li>- Hladilno mazalna sredstva</li> <li>- Hladilno mazalni principi</li> <li>- Smernice</li> </ul> <p>12. Produktivnost in ekonomičnost</p> <ul style="list-style-type: none"> <li>- Načrtovanje tehnoloških parametrov</li> <li>- Omejitve pri določevanju parametrov</li> <li>- Ekonomsko vrednotenje</li> </ul> <p>13. Optimiranje odrezovalnih procesov</p> <ul style="list-style-type: none"> <li>- Visoko produktivno odrezavanje</li> <li>- Visoko hitrostno odrezavanje</li> <li>- Optimiranje odrezovalnih procesov</li> </ul> <p>14. Posebni odrezovalni procesi</p> <ul style="list-style-type: none"> <li>- Hibridni postopki odrezavanja</li> <li>- Trajnostni elementi/smernice</li> <li>- Mikro odrezavanje</li> </ul> <p>15. Gostujoče predavanje z industrije</p> <ul style="list-style-type: none"> <li>- Gostujoče predavanje eksperta s postavljanja odrezovalnih tehnologij v industrijskih aplikacijah (BTS Company)</li> </ul>	<p>6. Nondefined cutting geometry</p> <ul style="list-style-type: none"> <li>- Processes with undefined cutting geometry</li> <li>- An overview of the kinematics spectrum of such processes</li> <li>- Process issues</li> </ul> <p>7. Thermal loads in machining</p> <ul style="list-style-type: none"> <li>- Thermal conditions in cutting</li> <li>- Influence on process</li> <li>- Influence on the machined surface integrity</li> </ul> <p>8. Tool-wear and tool-life</p> <ul style="list-style-type: none"> <li>- Wear of cutting tools</li> <li>- Wear mechanisms</li> <li>- Modeling of cutting tool-life</li> </ul> <p>9. Cutting tools</p> <ul style="list-style-type: none"> <li>- Cutting tool materials</li> <li>- Impact of cutting materials on the cutting process</li> <li>- Guidelines for their use</li> </ul> <p>10. Cutting tool coatings</p> <ul style="list-style-type: none"> <li>- Coatings of cutting tools</li> <li>- Functional properties of coatings</li> <li>- Influence of coatings on cutting geometry and process</li> </ul> <p>11. Cooling and lubrication of machining processes</p> <ul style="list-style-type: none"> <li>- Coolant and/or lubricants</li> <li>- Cooling lubrication principles</li> <li>- Guidelines</li> </ul> <p>12. Productivity and economy</p> <ul style="list-style-type: none"> <li>- Design of technological parameters</li> <li>- Constraints on parameter determination</li> <li>- Economic evaluation</li> </ul> <p>13. Optimization of machining processes</p> <ul style="list-style-type: none"> <li>- Higher performance machining</li> <li>- High speed machining</li> <li>- Optimization of machining processes</li> </ul> <p>14. Special/modern machining processes</p> <ul style="list-style-type: none"> <li>- Hybrid machining processes</li> <li>- Sustainable elements / guidelines</li> <li>- Micro machining</li> </ul> <p>15. Guest lecture by an expert from industry on machining technologies in industrial applications (BTS Company).</p>
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### 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:

<p>Cilji:</p> <ol style="list-style-type: none"> <li>1. Pridobiti poglobljena znanje o odrezovalnih procesih.</li> <li>2. Seznanitev z naprednimi in inovativnimi odrezovalnimi procesi in tehnologijami.</li> <li>3. Poznavanje postavljanja tehnologij, izračunov časov obdelav, obremenitev orodij, ter obstojnosti za optimalno delovanje procesov.</li> <li>4. Poznavanje modelov za popisovanje in napovedovanje odrezovalnih procesov</li> </ol> <p>Kompetence:</p> <ol style="list-style-type: none"> <li>1. S1-MAG: Temeljna usposobljenost in razumevanje področja odrezovalnih procesov, ki omogoča reševanje znanstvenih problemov in strokovnih izzivov.</li> <li>2. S7-MAG: Sposobnost uporabe sodobnih odrezovalnih procesov in njihovih raziskovalnih metod. Zmožnost njihovega optimiranja in prenašanja temeljnih znanj in spoznanj v prakso.</li> <li>3. P3-MAG: Obvladovanje temeljnih teoretičnih in aplikativnih znanj s širokega področja odrezovalnih</li> </ol>	<p>Objectives:</p> <ol style="list-style-type: none"> <li>1. To acquire in-depth knowledge of machining processes.</li> <li>2. Familiarity with advanced and innovative machining processes and technologies.</li> <li>3. Knowledge on technology development, cycle time calculations, tool loads, and tool-life for optimal process performance.</li> <li>4. Knowledge of models for enumerating and predicting behaviour of machining processes</li> </ol> <p>Competences:</p> <ol style="list-style-type: none"> <li>1. S1-MAG: Basic competence and understanding of the field of machining processes, which enables solving scientific problems and professional challenges.</li> <li>2. S7-MAG: Ability to use modern machining processes and their research methods. Ability to optimize them and bring them into practice.</li> <li>3. P3-MAG: Mastering the fundamental theoretical and applied knowledge of a wide range</li> </ol>
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procesov, ki so bistvena za obvladovanje področja proizvodnih tehnologij.	of machining processes that is essential to mastering manufacturing technology.
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### **Predvideni študijski rezultati:**

### **Intended learning outcomes:**

<p>Znanja:</p> <p>Z2: Poglobljeno teoretično, metodološko in analitično znanje s področja principov odrezovalnih procesov in tvorbe odrezkov, ki je osnova za zahtevno aplikativno delo.</p> <p>Spretnosti:</p> <p>S2.1 Poznavanje in obvladovanje zahtevnih / kompleksnih odrezovalnih procesov, in metodoloških orodij za modeliranje/napovedovanje obnašanja.</p> <p>S2.2 Načrtovanje tehnologij odrezavanja na podlagi reševanja problemov.</p> <p>S2.3 Sposobnost kritične refleksije in inovativnega nadgrajevanja.</p>	<p>Knowledge:</p> <p>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.</p> <p>Skills:</p> <p>S2.1 Knowledge and management of demanding / complex machining processes, and methodological tools for modeling / predicting behavior.</p> <p>S2.2 Designing machining technologies based on problem solving.</p> <p>S2.3 Ability to reflect critically and innovate upgrades.</p>
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### **Metode poučevanja in učenja:**

### **Learning and teaching methods:**

<p>P1 Avditorna predavanja z reševanjem izbranih – za področje značilnih – teoretičnih in praktično uporabnih primerov.</p> <p>P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri</p> <p>P4 Laboratorijske vaje v laboratoriju na obdelovalnih strojih</p> <p>P6 Interaktivna predavanja</p> <p>P8 Izdelava in predstavitev aplikativnih seminarskih nalog</p> <p>P15 Uporaba video vsebin kot priprava na predavanje in vaje.</p>	<p>P1 Lectures by solving selected - typical - theoretical and practical examples.</p> <p>P3 Practical classes where theoretical knowledge from lectures is supported by computational examples</p> <p>P4 Laboratory exercises in the laboratory on machine tools</p> <p>P6 Interactive Lectures</p> <p>P8 Design and presentation of applied seminar work</p> <p>P15 Use video content to prepare for lectures and tutorials.</p>
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**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
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**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]