NAČRTOVANJE ODREZAVANJA IN CAM

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Načrtovanje odrezavanja in CAM
Course title:	Planning of Machining and CAM
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - projektno aplikativni program, prva stopnja, visokošolski strokovni (od študijskega leta 2026/2027 dalje)	Proizvodne tehnologije (smer)	3. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0563512
Koda učne enote na članici/UL Member course code:	3061-V

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			40	4

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:	Izbirni strokovni predmet /Elective specialised course

Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	Prerequisites:
Izpolnjevanje pogojev za vpis v Visokošolski strokovni študijski program I. stopnje Strojništvo - Projektno aplikativni program.	Meeting the enrollment conditions for the MECHANICAL ENGINEERING - Project Oriented Applied Programme.

Vsebina:	Content (Syllabus outline):
1. Umestitev izdelovalnih postopkov • Delitev izdelovalnih postopkov • Izbira izdelovalnih postopkov • Določevanje strategij izdelave	1. Placement of manufacturing processes • Division of manufacturing processes • Selection of manufacturing processes • Manufacurting strategies definition

2. Uvod v tvorbo odrezka in odrezovalne postopke • Sodobni postopki odrezavanja • Prednosti in problematike • Produktivnost 3. Obdelovalni parametri in obdelana površina • Kakovost obdelane površine • Vpliv parametrov • Zagotavljanje geometrijskih toleranc 4. Aplikativni mehanizmi obrabe • Obraba rezalnih orodij • Mehanizmi obrabe • Obstojnost 5. Hladilno mazalni principi in trajnost • Hlajenje odrezovalnih procesov • Mazanje odrezovalnih procesov • Odnašanje odrezkov - vplivi na okolje, recikliranje in LCA 6. Načrtovanje izdelave izdelka • Faze v razvoju in izdelavi izdelka • Geometrijske entitete, ki določajo odrezovalne procese • Grobe/fine obdelave in eventuelne naknadne obdelave 7. Obdelovalne strategije • Izbira in načrtovanje izdelovalnih postopkov • Izbira in načrtovanje strategij obdelave • Substitucije obdelovalnih postopkov 8. CAM in digitalni dvojčki za načrtovanje obdelovalnih postopkov • Definiranje obdelovalnih poti • Uporaba CAM-a kot orodje za pripravo orodnih poti - virtualne simulacije 9. Osnove CAM postopka • CAM – priprava vpetja • CAM – definiranje orodij • CAM – koordinatni sistemi 10. Aplikacija CAM na različne odrezovalne procese • CAM – Struženje • CAM – Posebnosti • CAM – Simulacije 11. Aplikacija CAM na različne odrezovalne procese • CAM – frezanje • CAM – Posebnosti • CAM – Simulacije 12. Generiranje G-kode • G sekvence • Postprocesiranje • Vloga postprocesorja 13. Obdelovalnost kovin • Obdelovalnost jekel in železovih zlitin • Obdelovalnost visoko-temperaturnih zlitin 14. Obdelovalnost mehkejših materialov • Obdelovalnost barvnih kovin • Obdelovalnost nekovinskih materialov	2. Introduction to chip formation and machining processes • Modern machining procedures • Advantages and problems • Productivity 3. Machining parameters and machined surface • Quality of machined surface • Influence of parameters • Assurance of geometrical tolerances 4. Applicable wear mechanisms • Cutting tool wear • Wear mechanisms • Tool life 5. Cooling lubrication principles and sustainability • Cooling of machining processes • Lubricaiton of machining processes • Chip evacuation - influece on environment, recyclability and LCA 6. Product production planning • Phases in development and manufacturing of the products • Geometrical entities that define machining processes • Roughing/finishing and needed post processing 7. Manufacturing strategies • Selection and design of manufacturing processes • Selection and planning of machining strategies • Substitutions of machining processes 8. CAM and digital twins as a supported for design of manufacturing processes • Defnition of machining paths • Using CAM as a tool for toolpath generation - virtual simulations 9. Basics of CAM procedure • CAM – clamping preparation • CAM – defining the cutting tools • CAM – coordiante systems 10. CAM applicaiton on different machining processes • CAM – Turning • CAM – Specialities • CAM – Simulations 11. CAM applicaiton on different machining processes • CAM – Milling • CAM – Specialities • CAM – Simulations 12. G-code generation • G sequences • Postprocessing • Postprocessor role 13. Machinability of metals • Machining performance of steel and ferrous alloys • Machining performance of high temperature alloys

15. Optimiranje modernih odrezovalnih procesov z vidika trajnostnih načel • Optimiranje odrezovalnih procesov z vidika ekonomike - optimiranje odrezovalnih procesov z vidika vpliva na okolje/zdravje - ukrepi za zmanjševanje negativnih vidikov odrezavanja	14. Machinability of softer materials • Machining performance of non-ferrous metals • Machining performance of non-metallic materials 15. Optimisation of modern machining processes according to the sustainability aspects • Optimisation of machining processes based on economics - Optimisation of machining processes based on environment/health aspects - Measures to reduce the negative aspects of machining

Temeljna literatura in viri/Readings:

1. Z. Bi in X. Wang, Computer aided design and manufacturing. Hoboken, NJ; [New York, New York]: John Wiley & Sons, Inc.; ASME Press, 2020, str. XXI, 18 f., 617. ISBN 978-1-119-53421-1, [COBISS.SI-ID 44464899]
2. J. Kopač, Obdelovalni stroji, orodja in naprave: modulna gradnja obdelovalnih strojev. Ljubljana: Fakulteta za strojništvo, 2005, str. 224. ISBN 961-6238-99-X, [COBISS.SI-ID 222746880]
3. 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]
4. J. Kopač, Odrezavanje: teoretične osnove in tehnološki napotki. Ljubljana [i. e.] Domžale: [samozal.] J. Kopač, 2008, str. 26 ISBN 978-961-245-583-5, [COBISS.SI-ID 241209856]
5. 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]
6. S. Zhong: Mechanical Engineering and Green Manufacturing II, e-knjiga
7. S. Li: Mechanical Engineering and Green Manufacturing, e-knjiga.
8. S. McCabe, B. Nielsen: Green Manufacturing: What this involves and how to achieve success, Bite-sized books Ltd., 2021
9. J. Paulo Davim: Sustainable Manufacturing, Wiley-ISTE, 2013
10. J.W. Sutherlans, D.A. Dornfeld, B.S. Linke: Energy Efficient Manufacturing: Theory and Applications, Wiley, 2018.

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Pridobiti aplikativna znanja s področja odrezovalnih procesov. 2. Pridobiti aplikativna znanja s področja obdelovalnih strojev in CAM računalniško podprtega načrtovanja obdelovalnih strategij. 3. Seznanitev z naprednimi in inovativnimi odrezovalnimi procesi in tehnologijami. 4. Poznavanje postavljanja tehnologij, izračunov časov obdelav, obremenitev orodij, ter obstojnosti za optimalno delovanje procesov. 5. Dati študentu širši in multidisciplinarni pogled na obravnavano tematiko, predvsem v smislu iskanja trajnostnih in okolju prijaznih rešitev. **Kompetence**: 1. S5-PAP, P1-PAP, P3-PAP: Razumevanje fizikalnih zakonov gibanja obdelovalnih strojev in rezalnega orodja. 2. S1-PAP, S2-PAP, P1-PAP, P8-PAP: Sposobnost izbire primernih obdelovalnih strategij za dani izdelek in njegova umestitev na obdelovalni stroj/krmilnik.	**Objectives**: 1. To scquire applied knowledge in the field of machining processes. 2. To acquire applied knowledge in the field of machine tools and CAM computer-aided design of machining strategies. 3. Familiarity with advanced and innovative machining processes and technologies. 4. Knowledge of technology layout, cycle time calculations, tool loads and tool life fr optimal processes performance. 5. Give the student a wider and multidisciplinary overview of the specific R&D problem, especially in terms of finding sustainable and environmentally friendly solutions. **Competences**: 1. S5-PAP, P1-PAP, P3-PAP: Understanding the physical laws of motion of machine tools and cutting tools. 2. S1-PAP, S2-PAP, P1-PAP, P8-PAP: Ability to select suitable machining strategies for a given

3. S1-PAP, P3-PAP, P4-PAP: Sposobnost preverjanja dimenzijske ustreznosti obdelovancev/strojev. 4. S10-PAP, S13-PAP, S14-PAP: Razumevanje tujih strokovnih tekstov in zapisovanje dognanj. 5. S12-PAP: Sposobnost uporabe informacijsko-komunikacijske tehnologije. 6. P5-PAP: Pozna glavne okoljske omejitve in probleme. 7. P7-PAP: Pozna nekatera potrebna programska orodja za računalniško obdelavo podatkov.	product and its placement on machine tools/controller. 3. S1-PAP, P3-PAP, P4-PAP: Ability to check workpiece/machine tool dimensional entities. 4. S10-PAP, S13-PAP, S14-PAP: Understanding foreign professional texts and reporting of outcomes. 5. S12-PAP: The ability to use information and communications technology. 6. P5-PAP: Knowing the main environmental restrictions and problems. 7. P7-PAP: Knowing some software tools necessary for computer data processing.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Poglobljeno strokovno, teoretično in praktično znanje na področju gibanja obdelovalnih strojev, orodij in strategij obdelave, podprto s širšo teoretično in metodološko osnovo. Pri tem bo poseben poudarek namenjen poznavanju vsebin s področja trajnostne/zelene transformacije družbe in ustreznim digitalnim opolnomočenjem na strokovnem področju predmeta. **Spretnosti**: S1.1 Izvajanje kompleksnih operativno-strokovnih opravil, ki vključujejo tudi uporabo CAM programskih orodij. S1.2 Obvladovanje zahtevnih, kompleksnih delovnih procesov ob samostojni uporabi znanja na novih delovnih situacijah, CAM okoljih, in odrezovalnih strojih. S1.4 Osnova za izvirna dognanja/ stvaritve in kritično refleksijo. S1.11 Sprejemanje kompleksnosti in trajnosti v smislu sistemskega razmišljanja in reševanja problemov. S1.12 Načrtovanje trajnostne prihodnosti z upoštevanjem prilagodljivosti za prihajajoče izzive.	**Knowledge**: In-depth professional, theoretical and practical knowledge of the movement of machine tools, cutting tools and machining strategies, supported by a broader theoretical and methodological basis. In this context, particular emphasis will be placed on subject knowledge in the area of sustainable/green transformation of society and appropriate digital empowerment in the subject area. **Skills**: S1.1 Perform complex operational and professional tasks that also include the use of CAM software tools. S1.2 Mastering complex work processes with the independent use of knowledge in new work situations, CAM environments and machine tools. S1.4 Basis for original findings / creations and critical reflection. S1.11 Acceptance of complexity and sustainability in terms of systemic thinking and problem solving. S1.12 Planning of a sustainable future by considering flexibility for upcoming challenges.

Metode poučevanja in učenja:	**Learning and teaching methods:**
P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. P2 Obravnava snovi po urejeni in vnaprej razloženi sistematiki. P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P6 Interaktivna predavanja P7 Študij literature in razprava P8 Izdelava in predstavitev aplikativnih seminarskih nalog P10 Uporaba anket v realnem času P15 Uporaba video vsebin kot priprava na predavanja in vaje P19 Uporaba IKT orodij in tehnologije za povečanje interakcije med predavateljem/asistentom in študenti.	P1 Lectures by solving selected - typical for field - theoretical and practical examples. P2 Treatment of the substance according to an orderly and pre-interpreted systematics P3 Practical classes where theoretical knowledge from lectures is supported by computational examples P6 Interactive lectures P7 Literature studies and discussion P8 Design and presentation of applied seminar papers. P10 Use real-time surveys. P15 Use video content to prepare for lectures and tutorials. P19 Usage of ICT tools and technology for enhancement of lecturer-student interaction.

Načini ocenjevanja:	Delež/Weight	Assessment:
Teoretične vsebine (predavanja).	60,00 %	Theoretical content (lectures).
Delo na laboratorijskih vajah.	40,00 %	Laboratory work.

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. 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. [Print ed.]. Dec. 2022, vol. 84, str. 1478-1491, ilustr. ISSN 1526-6125. https://www.sciencedirect.com/science/article/pii/S1526612522007812, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=143838, DOI: 10.1016/j.jmapro.2022.1008. [COBISS.SI-ID 130224387]
2. KHANNA, Navneet, SHAH, Prassan, SARIKAYA, Murat, **PUŠAVEC, Franci**. Energy consumption and ecological analysis of sustainable and conventional cutting fluid strategies in machining 15–5 PHSS. Processes. [Online ed.]. July 2022, vol. 32, str. 1-13, ilustr. ISSN 2227-9717. https://www.sciencedirect.com/science/article/pii/S2214993722000306, DOI: 10.1016/j.susmat.202e00416. [COBISS.SI-ID 107961091]
3. STERLE, Luka, KRAJNIK, Peter, **PUŠAVEC, Franci**. The effects of liquid-CO2 cooling, MQL and cutting parameters on drilling performance. CIRP annals. 2021, vol. 70, iss. 1, str. 79-82, ilustr. ISSN 0007-8506. https://www.sciencedirect.com/science/article/pii/S0007850621000317, DOI: 10.1016/j.cirp.2021.04.007. [COBISS.SI-ID 74389507]
4. GRGURAŠ, Damir, STERLE, Luka, **PUŠAVEC, Franci**. Cutting forces and chip morphology in LCO2 + MQL assisted robotic drilling of Ti6Al4V. 18th CIRP Conference on Modeling of Machining Operations (CMMO), Ljubljana, Slovenia, June 15-17, 2021. [S. l.]: Elsevier, 2021. Vol. 102, str. 299-302, ilustr. Procedia CIRP, vol. 102. ISSN 2212-8271. https://www.sciencedirect.com/science/article/pii/S2212827121007940, DOI: 10.1016/j.procir.2021.09.051. [COBISS.SI-ID 83097859]
5. RODRIGUEZ, Iñigo, ARRAZOLA, P. J., CUESTA, Mikel, **PUŠAVEC, Franci**. Hole quality improvement in CFRP/Ti6Al4V stacks using optimised flow rates for LCO2 and MQL sustainable cooling/lubrication. *Composite structures*. Feb. 2024, vol. 329, [article no.] 117687, str. 1-17, ilustr. ISSN 1879-1085. https://www.sciencedirect.com/science/article/pii/S0263822323010334, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.compstruct.2023.117687. [COBISS.SI-ID 192029443]

Davorin Kramar:

1. **KRAMAR, Davorin,** CICA, Djordje. Modeling and optimization of finish diamond turning of spherical surfaces based on response surface methodology and cuckoo search algorithm. Advances in production engineering & management, ISSN 1854-6250, Sep. 2021, vol. 16, no. 3, str. 326-334, ilustr. http://apem-journal.org/Archives/2021/Abstract-APEM16-3_326-334.html, doi: 10.14743/apem2021.3.403. [COBISS.SI-ID 87359491]
2. MUŽENIČ, David, DUGAR, Jaka, **KRAMAR, Davorin**, JEZERŠEK, Matija, PUŠAVEC, Franci. Improvements in machinability of zinc oxide ceramics by laser-assisted milling. *Strojniški vestnik*. Oct. 2019, vol. 65, no. 10, str. 539-546, si 67, ilustr. ISSN 0039-2480. https://www.sv-jme.eu/article/improvements-in-machinability-of-zinc-oxide-ceramics-by-laser-assisted-milling/, Digitalna knjižnica Slovenije - dLib.si, DOI: 10.5545/sv-jme.2019.6133. [COBISS.SI-ID 16872987]
3. CICA, Djordje, ÇALIŞKAN, Halil, PANJAN, Peter, **KRAMAR, Davorin**. Multi-objective optimization of hard milling using taguchi based grey relational analysis. *Tehnički vjesnik : znanstveno-stručni časopis tehničkih fakulteta Sveučilišta u Osijeku*. 2020, vol. 27, no. 2, str. 513-519. ISSN 1330-3651. DOI: 10.17559/TV-20181013122208. [COBISS.SI-ID 13357315]
4. SPAIĆ, Obrad, KRIVOKAPIĆ, Zdravko, **KRAMAR, Davorin**. Development of family of artificial neural networks for the prediction of cutting tool condition. *Advances in production engineering & management*. June 2020, vol. 15, no. 2, str. 164-178, ilustr. ISSN 1854-6250. http://apem-journal.org/Archives/2020/Abstract-APEM15-2_164-178.html, Digitalna knjižnica Slovenije - dLib.si, DOI: 10.14743/apem2020.2.356. [COBISS.SI-ID 49477379]

5. CICA, Djordje, **KRAMAR, Davorin**. Analysis and optimization of the process parameters on surface roughness in ball burnishing of AISI O2 hardened steel. *International journal of advanced manufacturing technology*. 2023, vol. 128, iss. 1/2, str. 345–356, ilustr. ISSN 0268-3768. https://link.springer.com/article/10.1007/s00170-023-11910-3, DOI: 10.1007/s00170-023-11910-3. [COBISS.SI-ID 192510723]