# STATIKA IN DINAMIKA TEKOČIN

# UČNI NAČRT PREDMETA/COURSE SYLLABUS

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| **Predmet:** | Statika in dinamika tekočin |
| **Course title:** | Fluid statics and dynamics |
| **Članica nosilka/UL Member:** | UL FS |

| Študijski programi in stopnja | Študijska smer | Letnik | Semestri | Izbirnost |
|---|---|---|---|---|
| Strojništvo - razvojno raziskovalni program, prva stopnja, univerzitetni (od študijskega leta 2023/2024 dalje) | Ni členitve (študijski program) | 2. letnik | 1. semester | obvezni |

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| **Univerzitetna koda predmeta/University course code:** | 0562751 |
| **Koda učne enote na članici/UL Member course code:** | 2014-U |

| Predavanja /Lectures | Seminar /Seminar | Vaje /Tutorials | Klinične vaje /Clinical tutorials | Druge oblike študija /Other forms of study | Samostojno delo /Individual student work | ECTS |
|---|---|---|---|---|---|---|
| 45 | | 30 | | | 50 | 5 |

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| **Nosilec predmeta/Lecturer:** | Božidar Šarler, Boštjan Mavrič |

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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 |
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| | Vaje/Tutorial: | Slovenščina |

| **Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:** | **Prerequisites:** |
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| Izpolnjevanje pogojev za vpis v Univerzitetni študijski program I. stopnje Strojništvo - Razvojno raziskovalni program. | Meeting the enrollment conditions for the Academic study programme of Mechanical Engineering - Research and Development program. |

| **Vsebina:** | **Content (Syllabus outline):** |
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| 1. Uvod:<br>- cilji in namen predmeta,<br>- razvrstitev tokov,<br>- uporaba statike in dinamike tekočin v tehniki,<br>- predstavitev učnega programa,<br>- predstavitev učnih pripomočkov, virov in načina dela,<br>- predstavitev obveznosti študentov,<br>- napotki za uspešen študij.<br>2. Kinematika:<br>- gibanje kontinuuma, premik, hitrost, pospešek, snovni in prostorki odvod,<br>- Reynoldsov transportni izrek,<br>- deformacijski gradient in tenzor,<br>- tenzor vrtenja in raztegovanja,<br>- hitrost sremembe deformacijskega tenzorja.<br>3. Koncept napetosti:<br>- vlečni vektor in napetostni tenzor,<br>- ekstremne vrednosti napetosti,<br>- primeri napetostnih stanj.<br>4. Ohranitveni zakoni v Lagrangeovem in Eulerjevem sistemu opisa:<br>- ohranitev mase,<br>- ohranitev gibalne količine,<br>- ohranitev vrtilne količine,<br>- ohranitev energije,<br>- izvori in prenos sestavin,<br>- izvor in prenos entropije,<br>- integralska in diferencialna oblika splošnega ohranitvenega principa. | Introduction:<br>- goals and purpose of the course,<br>- classification of flows,<br>- use of fluid statics and dynamics in engineering,<br>- presentation of study programme,<br>- presentation of study aids, literature and way of working,<br>- presentation of student obligations,<br>- directions for successful study.<br>2. Kinematics:<br>- motion of continuum, displacement, velocity, acceleration, substantial and space derivative,<br>- Reynolds transport theorem,<br>- deformation gradient and tensor,<br>- rotation and stretching tensor,<br>- rate of change of deformation tensor.<br>3. Concept of stress:<br>- traction vector and stress tensor,<br>- extreme values of stress,<br>- examples of stress states.<br>4. Conservation laws in Lagrange and Euler system of description:<br>- mass conservation,<br>- momentum conservation,<br>- moment of momentum conservation,<br>- energy conservation,<br>- source and transport of species,<br>- source and transport of entropy,<br>- integral and differential form of general conservation principle. |

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| 5. Navier-Stokesove enačbe:<br>- izpeljava Navier-Stokesovih enačb,<br>- robni pogoji,<br>- ne-Newtonske tekočine.<br>6. Elementarna dinamika tekočin - Bernoullijeva enačba:<br>- predpostavke, omejitve in izpeljava Bernoulijeve enačbe,<br>- statični, stagnacijski, dinamični in celotni tlak,<br>- primeri praktične uporabe Bernoulijeve enačbe.<br>7. Dimenzijska analiza, podobnost in modeliranje:<br>- dimenzijska analiza,<br>- Buckinghamov Pi teorem in uporaba,<br>- brezdimenzijske skupine,<br>- koreliranje eksperimentalnih podatkov.<br>8. Viskozni tok v ceveh:<br>- splošne karakteristike toka v ceveh,<br>- popolnoma razvit laminarni tok,<br>- popolnoma razvit turbulentni tok,<br>- primeri uporabe.<br>9. Tok okoli potopljenih teles:<br>- značilnosti laminarnega in turbulentnega toka okoli potopljenih teles,<br>- mejna plast,<br>- dinamični upor,<br>- dinamični vzgon,<br>- primeri uporabe.<br>10. Tok v odprtih kanalih:<br>- značilnosti toka v odprtih kanalih,<br>- valovi,<br>- kanali s konstantno globino in raizčnimi variacijami globine,<br>- primeri uporabe.<br>11. Stisljivi tok:<br>- razvrstitev stisljivih tokov in poglavitne značilnosti,<br>- izentropni tok idelnega plina,<br>- neizentropni tok idealnega plina,<br>- primeri uporabe.<br>12. Turbulentni tok:<br>- razvrstitev in značilnosti turbulentnih tokov,<br>- Reynoldsovo povprečene Navier-Stokesove enačbe: model mešalne dolžine, modela k-epsilon in k-omega,<br>- formulacija velikih vrtincev, | 5. Navier-Stokes equations:<br>- derivation of Navier-Stokes equations,<br>- boundary conditions,<br>- non-Newtonian fluids.<br>6. Elementary fluid dynamics - Bernoulli equation:<br>- the assumptions, limitations and derivation of Bernoulli's equation,<br>- static, stagnation, dynamic and total pressure,<br>- examples of practical use of Bernoulli equation.<br>7. Dimensional analysis, similarity and modelling:<br>- dimensional analysis,<br>- Buckingham Pi theorem and use,<br>- non-dimensional groups,<br>- correlation of experimental data.<br>8. Viscous flow in ducts:<br>- general characteristics of flow in ducts,<br>- completely developed lminar flow,<br>- completely developed turbulent flow,<br>- examples of use.<br>9. Flow around immersed bodies:<br>- features of laminar and turbulent flow around immersed bodies,<br>- boundary layer,<br>- dynamic drag,<br>- dynamic lift,<br>- examples of use.<br>10. Flow in open channels:<br>- features of flow in open channels,<br>- waves,<br>- channels with constant depth and different depth variations,<br>- examples of use.<br>11. Compressible flow:<br>- classification of compressible flow and main characteristics,<br>- isentropic flow of ideal gas,<br>- non-isentropic flow of ideal gas,<br>- examples of use.<br>12. Turbulent flow:<br>- classification and features of turbulent flows,<br>- Reynolds averaged Navier-Stokes equations: mixing length model, k-epsilon and k-omega models,<br>- large eddy formulation, |

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| - neposredna formulacija,<br>- primeri uporabe.<br>13. Mikrofluidika in nanofluidika:<br>- razvrstitev in posebnosti mikroflidnih in nanofluidnih tokov,<br>- viskoznost, povšinska napetost,<br>- primeri uporabe.<br>14. Tekočine pod vplivom zunanjih polj:<br>- vrtenje in stresanje,<br>- elektromagnetna polje,<br>- ultrazvočno polje,<br>- primeri uporabe.<br>15. Zaključek:<br>- predvidena nadgradnja osvojenega znanja v okviru predmeta Računalniška dinamika tekočin,<br>- predvidena nadgradnja osvojenega znanja v okviru predmeta Večfazni sistemi. | - direct formulation,<br>- examples of use.<br>13. Microfluidics and nanofluidics:<br>- classification and specifics of microfluidic and nanofluidic flows,<br>- viscosity, surface tension,<br>- examples of use.<br>14. Fluids under influence of external fields:<br>- rotation and shaking,<br>- electromagnetic field,<br>- ultrasound field,<br>- examples of use.<br>15. Conclusion:<br>- Foreseen upgrades of the acquired knowledge in the course of Computational Fluid Dynamics,<br>- Foreseen upgrades of the acquired knowledge in the course Multiphase systems. |

**Temeljna literatura in viri/Readings:**


1. B.R. Munson, T.H. Okiishi, W.W. Huebsch, A.P. Rothmayer, Fundamentals of Fluid Mechanics, Wiley, Chichester, 2016.
2. C. Pozrikidis, Fluid Dynamics: Theory, Computation and Numerical Simulation, 2nd Edition, Springer, Berlin, 2009.
3. G.A. Holzapfel, Nonlinear Solid Mechanics: A Continuum Approach for Engineering, Wiley, Chichester, 2008.
4. C. Kleinstreuer, Microfluidics and Nanofluidics: Theory and Selected Applications, Wiley, Chichester, 2014.


| **Cilji in kompetence:** | **Objectives and competences:** |
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| Cilji:<br>1. Predstaviti osnove in uporabo statike in dinamike tekočin.<br>2. Predstaviti poglobljen teoretični ter metodološki pristop k reševanju različnih sistemov s tekočinami.<br>3. Predstaviti praktično uporabo statike in dinamike tekočin na številnih inženirskih primerih.<br>4. Navdušiti študente za nadaljni, bolj poglobljeni študij predstavljenih osnov.<br>Kompetence:<br>1. P1-RRP, P2-RRP: Biti sposoben razpoznave različnih sistemov s | Objectives:<br>1. Present the basics and application of fluid statics and dynamics.<br>2. To present an in-depth theoretical and methodological approach to solving different systems involving fluids.<br>3. Demonstrate the practical use of fluid static and dynamics on various engineering cases.<br>4. To inspire the students for further, more in-depth study of the presented fundamentals.<br>Competences:<br>1. P1-RRP, P2-RRP: Being able to |

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| tekočinami, njihovega teoretičnege opisa in metodologije obravnave.<br>2. P4-RRP: Biti sposoben reševanja širokega spektra problemov s tekočinami.<br>3. P6-RRP: Biti sposoben optimizacije inženirskih sistemov s tekočinami glede na učinkovitost, kvaliteto in vpliv na okolje. | identify different systems involving fluids, their theoretical description and approach methodology.<br>2. P4-RRP: Being able to solve a wide range of fluid induced problems.<br>3. P6-RRP: Being able to optimize engineering systems involving fluids in terms of efficiency, quality and environmental impact.. |

**Predvideni študijski rezultati:** | **Intended learning outcomes:**

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| Znanja:<br>Z1: Poglobljeno strokovno teoretično in praktično znanje statike in dinamike tekočin, podprto s primerno široko teoretično in metodološko osnovo.<br>Spretnosti:<br>S1.1 Izvajanje kompleksnih operativno - strokovnih opravil, ki vključujejo tudi uporabo metodoloških orodij.<br>• Hitra prilagoditev reševanju različnih sistemov s tekočinami.<br>S1.2 Obvladovanje zahtevnih, kompleksnih delovnih procesov ob samostojni uporabi znanja v novih delovnih situacijah.<br>• Samostojna uporaba znanja pri snovanju inženirskih sistemov s tekočinami.<br>• Reševanje problemov s tekočinami glede na učinkovitost, kvaliteto in vpliv na okolje.<br>• Biti sposoben nadaljnjega, samostojnega študija predstavljenih osnov. | Knowledge:<br>Z1: Thorough professional theoretical and practical knowledge of fuid statics and dynamics, supported with an appropriately broad theoretical and methodological basis.<br>Skills:<br>S1.1 Executing complex operational-professional tasks that incorporate usage of methodological tools.<br>- Rapid adaptation to solving of various systems involving fluids.<br>S1.2 Mastering demanding and complex work processes by independent usage of knowledge in new working situations.<br>- Independent use of knowledge in the design of engineering systems involving fluids.<br>- Solving problems with fluids in terms of efficiency, quality and environmental impact.<br>- Be able to further, independently study the presented fundamentals. |

**Metode poučevanja in učenja:** | **Learning and teaching methods:**

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| P1: Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov.<br>P3: Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. | P1: Auditorial lectures with solving selected field-specific theoretical and applied use cases.<br>P3: Auditorial exrecises, in which the theoretical content from the lectures is supplemented with the practical examples. |

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| P4: Laboratorijske vaje z namenskimi didaktičnimi pripomočki: Reološke lastnosti kapljevin (Hoepplerjev viskozimeter, Vibracijski reometer), določitev prehoda iz laminarnega v turbulentni tok (Reynoldsov poskus), torni padec tlaka v laminarnem in turbulentnem toku nestisljivega fluida (namenska testna sekcija z vgrajenimi piezouporovnimi tlačnimi zaznavali in sistemom za zajem podatkov), porazdelitev hitrosti in lastnosti turbulence pri toku zraka v cevi (namenska testna sekcija z ventilatorjem ter CTA sistemom za lokalne meritve hitrosti).<br>P5: Uporaba študijskega gradiva v obliki (učbenik za predavanja).<br>P5: Uporaba študijskega gradiva v obliki (učbenik za vaje).<br>P6: Interaktivna predavanja.<br>P14: Virtualni eksperimenti.<br>P15: Uporaba video vsebin kot priprava na predavanja in vaje. | P4: Laboratory exercises with special-purpose didactic devices: Rheological properties of liquids (Hoeppler viscosimeter, Vibrational rheometer), Characterisation of laminar to turbulent flow transition (Reynolds experiment), frictional pressure drop in laminar and turbulent flow of incompressible fluid (purpose built test section with piezoresistive pressure sensors and data acquisition system), velocity distribution and turbulence properties of air flow in a pipe (purpose built test section with a fan and CTA system for local velocities measurements).<br>P5: Application of study material (textbook for lectures).<br>P5: Application of study material (textbook for exercises).<br>P6: Interactive lectures.<br>P14: Virtual experiments.<br>P15: Application of videos for preparation to the lectures and exercises. |

| **Načini ocenjevanja:** | **Delež/ Weight** | **Assessment:** |
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| Pisni izpit | 50,00 % | Written exam |
| Naloge | 50,00 % | Exercises |

**Reference nosilca/Lecturer's references:**

**Božidar Šarler:**

1. TALAT, Nazia, MAVRIČ, Boštjan, BELŠAK, Grega, HATIĆ, Vanja, BAJT, Saša, **ŠARLER, Božidar**. Development of meshless phase field method for two-phase flow. International Journal of Multiphase Flow. [Online ed.]. Nov. 2018, vol. 108, f. 169-180, ilustr. ISSN 1879-3533. https://www.sciencedirect.com/science/article/pii/S0301932218302258?via%3Dihub, DOI: 10.1016/j.ijmultiphaseflow.2018.06.003. [COBISS.SI-ID 16111387]
2. ZAHOOR, Rizwan, BELŠAK, Grega, BAJT, Saša, **ŠARLER, Božidar**. Simulation of liquid micro-jet in free expanding high-speed co-flowing gas streams. Microfluidics and nanofluidics. Aug. 2018, vol. 22, 1-20 f, ilustr. ISSN 1613-498 https://link.springer.com/content/pdf/10.1007%2Fs10404-018-2110-0.pdf, DOI: 10.1007/s10404-018-2110-0. [COBISS.SI-ID 16174107]
3. OBERTHUER, Dominik, **ŠARLER, Božidar**, BELŠAK, Grega, MAČEK, Marjan. Double-flow focused liquid injector for efficient serial femtosecond

crystallography. Scientific reports. 2017, vol. 7, str. 1-7, ilustr. ISSN 2045-2322. http://www.nature.com/articles/srep44628.pdf, DOI: 10.1038/srep44628. [COBISS.SI-ID 1296042]

4. HATIĆ, Vanja, MAVRIČ, Boštjan, KOŠNIK, Nejc, **ŠARLER, Božidar**. Simulation of direct chill casting under the influence of a low-frequency electromagnetic field. Applied mathematical modelling. [Print ed.]. 2017, vol. 54, str. 170-188, ilustr. ISSN 0307-904X. http://www.sciencedirect.com/science/article/pii/S0307904X17305863, DOI: 10.1016/j.apm.2017.09.03 [COBISS.SI-ID 15664923]
5. VERTNIK, Robert, **ŠARLER, Božidar**. Local collocation approach for solving turbulent combined forced and natural convection problems. Advances in applied mathematics and mechanics. 2011, vol. 3, no. 3, str. 259-279. ISSN 2070-0733. [COBISS.SI-ID 1781243]

**Boštjan Mavrič:**

1. **MAVRIČ, Boštjan, ŠARLER, Božidar. Equivalent-PDE based stabilization of strong-form meshless methods applied to advection-dominated problems. Engineering analysis with boundary elements. 2020, vol. 113, str. 315-327, ilustr. ISSN 0955-7997. https://www.sciencedirect.com/science/article/pii/S0955799720300205?via%3Dihub, DOI: 10.1016/j.enganabound.2020.01.014. [COBISS.SI-ID 17037339], [JCR, SNIP, WoS do 26. 10. 2022: št. citatov (TC): 3, čistih citatov (CI): 3, čistih citatov na avtorja (CIAu): 1,50, Scopus do 28. 7. 2022: št. citatov (TC): 4, čistih citatov (CI): 4, čistih citatov na avtorja (CIAu): 2,00], kategorija: 1A2 (Z, A1/2); uvrstitev: SCIE, Scopus, MBP (INSPEC, COMPENDEX, MSN, ASFA, PUBMED); tip dela je verificiral OSICN, točke: 49.62, št. avtorjev: 2**
2. **TALAT, Nazia, MAVRIČ, Boštjan, BELŠAK, Grega, HATIĆ, Vanja, BAJT, Saša, ŠARLER, Božidar. Development of meshless phase field method for two-phase flow. International Journal of Multiphase Flow. Nov. 2018, vol. 108, f. 169-180, ilustr. ISSN 1879-3533. https://www.sciencedirect.com/science/article/pii/S0301932218302258?via%3Dihub; DOI: 10.1016/j.ijmultiphaseflow.2018.06.003. [COBISS.SI-ID 16111387], [JCR, SNIP, WoS do 21. 11. 2022: št. citatov (TC): 15, čistih citatov (CI): 7, čistih citatov na avtorja (CIAu): 1,17, Scopus do 14. 2. 2023: št. citatov (TC): 17, čistih citatov (CI): 8, čistih citatov na avtorja (CIAu): 1,33], kategorija: 1A1 (Z, A', A1/2); uvrstitev: SCIE, Scopus, MBP (INSPEC, COMPENDEX, MSN); tip dela je verificiral OSICN, točke: 16.87, št. avtorjev: 6**
3. **HATIĆ, Vanja, MAVRIČ, Boštjan, ŠARLER, Božidar. Meshless simulation of a lid-driven cavity problem with a non- Newtonian fluid. Engineering analysis with boundary elements. Oct. 2021, vol. 131, str. 86-99, ilustr. ISSN 0955-7997. https://www.sciencedirect.com/science/article/pii/S0955799721001715, DOI: 10.1016/j.enganabound.2021.06.015. [COBISS.SI-ID 69191939], [JCR, SNIP, WoS do 27. 2. 2023: št. citatov (TC): 3, čistih citatov (CI): 2, čistih citatov na avtorja (CIAu): 0,67, Scopus do 14. 2. 2023: št. citatov (TC): 3, čistih citatov (CI): 2, čistih citatov na avtorja (CIAu): 0,67], kategorija: 1A1 (Z, A', A1/2); uvrstitev: SCIE, Scopus, MBP (INSPEC, COMPENDEX, MSN, ASFA, PUBMED); tip dela je verificiral**

**OSICN, točke: 33.9, št. avtorjev: 3**

4. **DOBRAVEC, Tadej, MAVRIČ, Boštjan, ŠARLER, Božidar. Reduction of discretisation-induced anisotropy in the phase-field modelling of dendritic growth by meshless approach. Computational materials science. [Print ed.]. 2020, vol. 172, str. 1-12, ilustr. ISSN 0927-0256. https://doi.org/10.1016/j.commatsci.2019.109166, DOI: 10.1016/j.commatsci.2019.109166 . [COBISS.SI-ID 1527466], [JCR, SNIP, WoS do 1. 12. 2022: št. citatov (TC): 10, čistih citatov (CI): 6, čistih citatov na avtorja (CIAu): 2,00, Scopus do 14. 2. 2023: št. citatov (TC): 11, čistih citatov (CI): 7, čistih citatov na avtorja (CIAu): 2,33], kategorija: 1A3 (Z); uvrstitev: SCIE, Scopus, MBP (INSPEC, COMPENDEX, PUBMED); tip dela je verificiral OSICT, točke: 26.6, št. avtorjev: 3**
5. **ŠARLER, Božidar, DOBRAVEC, Tadej, GLAVAN, Gašper, HATIĆ, Vanja, MAVRIČ, Boštjan, VERTNIK, Robert, CVAHTE, Peter, GREGOR, Filip, JELEN, Marina, PETROVIČ, Marko. Multi-physics and multi-scale meshless simulation system for direct-chill casting of aluminium alloys. Strojniški vestnik. Nov.-Dec. 2019, vol. 65, no. 11/12, str. 658-670, si 85, ilustr. ISSN 0039-2480. https://www.sv-jme.eu/sl/article/multi-physics-and-multi-scale-meshless-simulation-system- for-direct-chill-casting-of-aluminium-alloys/, DOI: 10.5545/sv-jme.2019.6350. [COBISS.SI-ID 3385188], [JCR, SNIP, WoS do 26. 10. 2022: št. citatov (TC): 5, čistih citatov (CI): 1, čistih citatov na avtorja (CIAu): 0,10, Scopus do 14. 2. 2023: št. citatov (TC): 5, čistih citatov (CI): 1, čistih citatov na avtorja (CIAu): 0,10], kategorija: 1A3 (Z); uvrstitev: SCIE, Scopus, MBP (INSPEC, COMPENDEX); tip dela je verificiral OSICT, točke: 6.24, št. avtorjev: 10**