

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Sestavljena gonila v mobilni tehniki
Course title:	COMPLEX POWERTRAINS IN MOBILE MACHINERY
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Konstruiranje (smer)	2. letnik	1. semester

Univerzitetna koda predmeta/University course code:	0566884
Koda učne enote na članici/UL Member course code:	6031-M

Predavanja	Seminar	Vaje	Klinične vaje	Druge oblike študija	Samostojno delo	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	Jernej Klemenc, Marko Nagode, Simon Oman
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Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Konstruiranje, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Design Engineering, which is an elective specialised course in other fields of study.
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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.
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Vsebina: **Content (Syllabus outline):**

1. Predavanja: Delitev mobilne tehnike: <ul style="list-style-type: none"> - Zračna mobilna tehnika; - Vodna mobilna tehnika; - Kopenska mobilna tehnika; - Posebnosti posameznih vrst mobilne tehnike. 	1. Lecture: Partition of mobile machinery: <ul style="list-style-type: none"> - Aircrafts; - Water vessels; - Ground vehicles; - Specialities of different types of mobile machinery.
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<p>2. Predavanje: Uvod v kopensko mobilno tehniko:</p> <ul style="list-style-type: none"> - Tirna kolesna vozila – zahtevani pogoji za stabilnost vožnje tirnih vozil; - Cestna in izven-cestna vozila; - Gosenična vozila. <p>3. Predavanje: Bilanca vlečnih sil za vozila s kolesi:</p> <ul style="list-style-type: none"> - Kotalni upor; - Zračni upor; - Upor strmine; - Upor priklopnika. - Določitev mejnih vozniških karakteristik z metodo navorov in moči. <p>4. Predavanje: Večstopenjska zobniška gonila za prilagoditev zunanje karakteristike motorjev z notranjim zgorevanjem izdelani vozni karakteristiki:</p> <ul style="list-style-type: none"> - Osnovna geometrija čelnih zobnikov z ravnim in poševnim evolventnim ozobjem; - Debelina zoba na poljubnem krogu. <p>5. Predavanje: Večstopenjska zobniška gonila za prilagoditev zunanje karakteristike motorjev z notranjim zgorevanjem izdelani vozni karakteristiki:</p> <ul style="list-style-type: none"> - Korekcija evolventnih zobniških dvojic za doseganje enotne medosne razdalje; - Vpliv korekcije evolventnega ozobja na korensko in bočno trdnost zobnikov. <p>6. Predavanje: Večstopenjska zobniška gonila za prilagoditev zunanje karakteristike motorjev z notranjim zgorevanjem izdelani vozni karakteristiki:</p> <ul style="list-style-type: none"> - Avtomatski menjalnik kot sestav planetnih gonil; - Izpeljava osnovne enačbe planetnega gonila; - Določitev notranjih in zunanjih prestavnih razmerij planetnega gonila. <p>7. Predavanje: Večstopenjska zobniška gonila za prilagoditev zunanje karakteristike motorjev z notranjim zgorevanjem izdelani vozni karakteristiki:</p> <ul style="list-style-type: none"> - Kotalna in sklopna moč planetnega gonila; - Določitev toka moči skozi planetno gonilo z upoštevanjem izgub. <p>8. Predavanje: Vzdolžno gibanje vozila:</p> <ul style="list-style-type: none"> - Tok moči med pogonskimi in gnanimi kolesi; - Vozila z več pogonskimi premami; - Distribucija navora in moči med več pogonskimi premami. <p>9. Predavanje: Vzdolžno gibanje vozila:</p> <ul style="list-style-type: none"> - Problem uravnoteženja navorov med pogonskimi premami; - Problem uravnoteženja vrtilnih hitrosti pogonskih prem; - Diferencialno planetno gonilo s stožčastimi zobniki; - Diferencialno planetno gonilo z vijačnimi in polžastimi zobniki – Torsen diferencial. <p>10. Predavanje: Diferencialno planetno gonilo s stožčastimi zobniki:</p> <ul style="list-style-type: none"> - Geometrija stožčastih zobniških dvojic; 	<p>2. Lecture: Introduction to ground vehicles:</p> <ul style="list-style-type: none"> - Railway vehicles – necessary conditions for driving stability of railway vehicles; - Road- and off-road vehicles; - Caterpillar vehicle. <p>3. Lecture: Traction-force balance for wheeled vehicles:</p> <ul style="list-style-type: none"> - Rolling resistance; - Air-drag resistance; - Inclination resistance; - Trailer resistance. - Determination of the limit driving characteristics with the method of torques or power. <p>4. Lecture: Multi-level gear transmissions for adapting an output characteristics of the internal-combustion engines to the ideal traction characteristic:</p> <ul style="list-style-type: none"> - Basic geometry of spur- and helical gears with involute tooth flank; - Tooth thickness at arbitrary diameter. <p>5. Lecture: Multi-level gear transmissions for adapting an output characteristics of the internal-combustion engines to the ideal traction characteristic:</p> <ul style="list-style-type: none"> - Correction of involute gears for equal axial distances; - Influence of a gear correction to the root- and contact strength of gears. <p>6. Lecture: Multi-level gear transmissions for adapting an output characteristics of the internal-combustion engines to the ideal traction characteristic:</p> <ul style="list-style-type: none"> - Automatic transmission as an assembly of planetary gears; - Derivation of a basic equation of a planetary gear; - Determination of the inner (stable) and outer gear ratios for the planetary gear. <p>7. Lecture: Multi-level gear transmissions for adapting an output characteristics of the internal-combustion engines to the ideal traction characteristic:</p> <ul style="list-style-type: none"> - Rolling and switching power of a planetary gear; - Power-flow through a planetary gear by considering the power losses. <p>8. Lecture: Longitudinal vehicle movement:</p> <ul style="list-style-type: none"> - Power-flow between the traction and no-traction wheels; - Vehicles with multiple traction axles; - Torque and power distribution among multiple traction axles. <p>9. Lecture: Longitudinal vehicle movement:</p> <ul style="list-style-type: none"> - Problem of torque balancing among the traction axles; - Problem of angular-velocity balancing among the traction axles; - Differential planetary gear with bevel gears; - Differential planetary gear with worm gears – Torsen differential gear. <p>10. Lecture: Differential planetary gear with bevel gears:</p>
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<ul style="list-style-type: none"> - Plani stožčasti zobnik; - Sile na ozobju pri stožčastih zobnikih. <p>11. Predavanje: Diferencialno planetno gonilo z vijačnimi in polžastimi zobniki:</p> <ul style="list-style-type: none"> - Geometrija vijačnih in polžastih zobniških dvojic; - Izkoristek vijačnih in polžastih zobniških dvojic; - Sile na ozobju pri vijačnih in polžastih zobnikih. <p>12. Predavanje: Posebne izvedbe diferencialnih planetnih gonil v mobilni tehniki:</p> <ul style="list-style-type: none"> - Samozaporni diferencial; - Avtomatski samozaporni diferencial; - Kombinirano planetno gonilo za vektoriranje navora. <p>13. Predavanje: Pnevmatika kot povezava vozila z vozno površino:</p> <ul style="list-style-type: none"> - Pnevmatika kot toro gonilo; - Bočna elastičnost pnevmatike. <p>14. Predavanje: Pnevmatika kot povezava vozila z vozno površino:</p> <ul style="list-style-type: none"> - Kinematika vožnje v ovinek; - Bočna stabilnost vozila pri vožnji v ovinek. <p>15. Predavanje: Pnevmatika kot povezava vozila z vozno površino:</p> <ul style="list-style-type: none"> - Mikro zdrs pnevmatike pri pospeševanju; - Mikro zdrs pnevmatike pri zaviranju; - Mikro zdrs pnevmatike pri vožnji v ovinek. 	<ul style="list-style-type: none"> - Geometry of bevel gears; - Plane bevel gear; - Forces acting on a pair of bevel gears. <p>11. Lecture: Differential planetary gear with worm gears:</p> <ul style="list-style-type: none"> - Geometry of worm gears; - Power efficiency of worm gears; - Forces acting in a contact of a worm gear and its helical gear wheel. <p>12. Lecture: Special geometries of differential planetary gears in mobile machinery:</p> <ul style="list-style-type: none"> - Self-locking differential gear; - Automatic self-locking differential gear; - Combined planetary gear assembly for torque vectoring. <p>13. Lecture: Pneumatic tyre as a link between a ground vehicle and a driving surface:</p> <ul style="list-style-type: none"> - Pneumatic tyre as a friction wheel; - Cornering stiffness of the pneumatic tyre. <p>14. Lecture: Pneumatic tyre as a link between a ground vehicle and a driving surface:</p> <ul style="list-style-type: none"> - Kinematics of driving through a bend; - Lateral stability of the vehicle when driving through the bend. <p>15. Lecture: Pneumatic tyre as a link between a ground vehicle and a driving surface:</p> <ul style="list-style-type: none"> - Micro-slip of the pneumatic tyre during acceleration; - Micro-slip of the pneumatic tyre during deceleration; - Micro-slip of the pneumatic tyre when driving through the bend.
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Temeljna literatura in viri/Readings:

1. Klemenc J. Dinamika vozil – učbenik. Ljubljana: UL, Fakulteta za strojništvo, 2019.
2. Granzow C. ZF Vector Drive – better driving dynamics and driving safety through Torque Vectoring. Praesentation Praktischer Entwurf mechatronischer Systeme, Karlsruhe 13.12.2013.
3. Wong J.Y. Theory of ground vehicles – 3rd edition. John Wiley & Sons, 2001.
4. Flašker J., Glodež S., Ren Z. Zobniška gonila. Založba Pasadena, 2010.

Cilji in kompetence:

Objectives and competences:

<p>Cilji:</p> <ol style="list-style-type: none"> 1. Spoznati osnovne principe uravnoteženja navorov in moči v mobilni tehniki. 2. Spoznati napredno teorijo različnih vrst zobniških gonil in tornih gonil s pnevmatiko. 3. Spoznati ključne elemente pogonskih sistemov cestnih in izven-cestnih vozil. 4. Spoznati kinematične osnove gibanja kopenskih 	<p>Objectives:</p> <ol style="list-style-type: none"> 1. To learn basic principles of torque and power balancing in mobile machinery. 2. To learn advanced theory of different gear transmissions and friction drives with a pneumatic tyre. 3. To get a knowledge of key powertrain elements of road- and off-road vehicles.
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<p>vozil.</p> <p>5. Spoznati principe določevanja mejnih vozni karakteristik kolesnih vozil.</p> <p>Kompetence:</p> <ol style="list-style-type: none"> 1. S1-MAG: Sposobnost za opredelitev, razumevanje temeljnih znanstvenih problemov in ustvarjalno reševanje strokovnih izzivov na področju mobilne tehnike. 2. S5-MAG: Sposobnost predmetno-specifičnega strokovnega sporazumevanja in pisnega izražanja tudi v mednarodnem prostoru. 3. P1-MAG: Sposobnost za nadgrajevanje in uporabo temeljnih strojniških znanj ter njihovo razvojno-tehniško implementacijo na področju mobilne tehnike. 4. P4-MAG: Sposobnost fizikalnega, matematičnega in numeričnega modeliranja vožnje cestnih in izven-cestnih vozil ter sposobnost kritične analize rezultatov. 5. P5-MAG: Sposobnost samostojnega pridobivanja novih znanj in veščin. 	<ol style="list-style-type: none"> 4. To learn basics of ground-vehicle driving kinematics. 5. To learn principles for assessing the limit driving conditions of ground vehicles. <p>Competences:</p> <ol style="list-style-type: none"> 1. S1-MAG: The ability to define and understand fundamental scientific problems and to creatively deal with professional challenges in the field of mobile machinery. 2. S5-MAG: The ability of subject-specific professional communication and express oneself in writing, also internationally. 3. P1-MAG: The ability to upgrade and use the fundamental mechanical engineering knowledge, including its developmental-technical implementation in the field of mobile machinery. 4. P4-MAG: The ability for physical, mathematical and numerical modelling of ground vehicles driving kinematics, including a developed ability to critically analyse the results. 5. P5-MAG: The ability to autonomously acquire new knowledge and skills.
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Predvideni študijski rezultati:

<p>Znanja:</p> <p>Z2: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja, ki je osnova za zelo zahtevno strokovno delo:</p> <ul style="list-style-type: none"> • Razumevanje zveze med potrebami in viri moči v mobilni tehniki. • Razumevanje delovanja naprednih pogonov v mobilni tehniki. • Razumevanje teoretičnih in praktičnih osnov za koncipiranje in oblikovanje različnih elementov in sestavov kopenskih vozil. <p>Spretnosti:</p> <p>S2.1 Obvladovanje zelo zahtevnih, kompleksnih delovnih procesov in metodoloških orodij na specializiranih področjih:</p> <ul style="list-style-type: none"> • Sposobnost analitičnega in eksperimentalnega ocenjevanja energetske učinkovitosti vozil. <p>S2.3 Sposobnost izvirnih dognanj/stvaritev in kritične refleksije:</p> <ul style="list-style-type: none"> • Sposobnost izvajanja raziskav na področjih pogonov in nosilnih struktur v mobilni tehniki. 	<p>Knowledge:</p> <p>Z2: Thorough theoretical, methodological and analytical knowledge with elements of a research work that form a basis for very demanding professional work:</p> <ul style="list-style-type: none"> • Understanding a relationship between the power needs and sources in mobile machinery. • Functional understanding of advanced powertrains in mobile machinery. • Understanding of theoretical and practical basics for conceptualisation and design of different elements and assemblies of ground vehicles. <p>Skills:</p> <p>S2.1 Mastering very demanding and complex work processes and methodological tools in specialised professional fields:</p> <ul style="list-style-type: none"> • Ability of analytical and experimental assessment of the vehicle's power efficiency. <p>S2.3 Ability of unique innovations and critical reflections:</p> <ul style="list-style-type: none"> • Ability of research in the field of the powertrains and load-carrying structures in mobile machinery.
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Metode poučevanja in učenja:**Learning and teaching methods:**

<ol style="list-style-type: none"> 1. P1: Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. 2. P7: Študij literature in razprava. 3. P3: Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. 4. P4: Laboratorijske vaje z namenskimi didaktičnimi pripomočki (uporaba hibridnega vozila, razvitega na FS). 5. P14: Virtualni eksperimenti. 	<ol style="list-style-type: none"> 1. P1: Auditorial lectures with solving selected field-specific theoretical and applied use cases. 2. P7: Literature study and discussion. 3. P3: Auditorial exercises, in which theoretical content from the lectures is supplemented with practical examples. 4. P4: Laboratory exercises with special-purpose didactic devices (application of an own-developed hybrid vehicle). 5. P14: Virtual experiments.
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Načini ocenjevanja:**Delež/Weight****Assessment:**

Teoretična znanja (pisni kolokviji in izpit z opcijskim ustnim zagovorom)	50,00 %	Theoretical knowledge (written colloquia and exam with an optional oral examination)
Avditorne vaje (seminarska poročila s predstavitvami)	15,00 %	Auditorial exercises (seminar reports with presentations)
Laboratorijske vaje (poročila)	15,00 %	Laboratory exercises (reports)
Pisni preskus praktičnega znanja, osvojenega na vajah	20,00 %	Written examination of practical knowledge that was acquired in exercises.

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

1. TOMAŽINČIČ, Dejan, VESENJAK, Matej, KLEMENC, Jernej. Prediction of static and low-cycle durability of porous cellular structures with positive and negative Poisson's ratios. Theoretical and Applied Fracture Mechanics. Apr. 2020, vol. 106 (102479), str. 1-13, DOI: 10.1016/j.tafmec.2020.102479. [COBISS.SI-ID 22988310]
2. ŠKRLEC, Andrej, KLEMENC, Jernej. Estimating the strain-rate-dependent parameters of the Cowper-Symonds and Johnson-Cook material models by Taguchi arrays. Strojniški vestnik, Apr. 2016, vol. 62, no. 4, str. 220-230, SI 37, doi: 10.5545/sv-jme.2015.3266. [COBISS.SI-ID 14571547]
3. ŠKRLEC, Andrej, KLEMENC, Jernej, FAJDIGA, Matija. Parameter identification for a low-density-foam material model using numerical optimisation procedures. Engineering computations, 2014, vol. 31, iss. 7, str. 1532-1549, doi: 10.1108/EC-03-2013-0100. [COBISS.SI-ID 13681947]
4. KLEMENC, Jernej, WAGNER, Andrej, GRUBIŠIČ, Vatroslav, FAJDIGA, Matija. Schienenzustand und Gleitreibungszahl zwischen Rad und Schiene_. ETR, ISSN 0013-2845, 2011, vol. 60, iss. 11, str. 34-38. [COBISS.SI-ID 12166427]
5. ŠKRLEC, Andrej, FRANKO, Mitja, KLEMENC, Jernej. Simulacija utrujanja glavne roke obešenja in optimizacija nosilca armaturne plošče : numerična in eksperimentalna analiza (končno poročilo). Ljubljana: Fakulteta za strojništvo, Laboratorij za vrednotenje konstrukcij, okt. 2017. 59 f. [COBISS.SI-ID 15759387]

Marko Nagode:

1. ZALETELJ, Henrik, HAESEN, Vik, DEDENE, L., FAJDIGA, Gorazd, NAGODE, Marko. High cycle fatigue of welded joints with aging influence. Materials & design. Mar. 2013, vol. 45, str. 190-197, ilustr. ISSN 0264-1275. DOI: 10.1016/j.matdes.2012.08.059. [COBISS.SI-ID 12456731]
2. ŠERUGA, Domen, NAGODE, Marko. Comparative analysis of optimisation methods for linking material parameters of exponential and power models : an application to cyclic stress-strain curves of ferritic stainless steel. Proceedings of the Institution of Mechanical Engineers, Proceedings part L, Journal of

materials - design and applications., ISSN 1464-4207, 2019, vol. 233, iss. 9, str. 1802-1813, ilustr.
<http://journals.sagepub.com/doi/full/10.1177/1464420718790829>, doi: 10.1177/1464420718790829.
[COBISS.SI-ID 16189723]

3. OMAN, Simon, NAGODE, Marko. The influence of piston shape on air-spring fatigue life. *Fatigue & fracture of engineering materials & structures*, ISSN 8756-758X, 2018, vol. 41, iss. 5, str. 1019-1031, ilustr.
<http://onlinelibrary.wiley.com/doi/10.1111/ffe.12748/epdf>, doi: 10.1111/ffe.12748. [COBISS.SI-ID 15773211]
4. ZALETELJ, Henrik, FAJDIGA, Gorazd, NAGODE, Marko. Low cycle fatigue of welded joints with aging influence. *Materials Science & Engineering.A, Structural materials: Properties, Microstructure and Processing*. [Print ed.]. Mar. 2013, vol. 564, str. 478-484, ilustr. ISSN 0921-5093. DOI: 10.1016/j.msea.2012.11.101. [COBISS.SI-ID 12558875]
5. OMAN, Simon, FAJDIGA, Matija, NAGODE, Marko. Estimation of air-spring life based on accelerated experiments. *Materials & design*, ISSN 0264-1275, 2010, vol. 31, iss. 8, str. 3859-3868, doi: 10.1016/j.matdes.2010.03.044. [COBISS.SI-ID 11362075]

Oman Simon:

1. BEŠTER, Tomaž, OMAN, Simon, NAGODE, Marko. Determining influential factors for an air spring fatigue life. *Fatigue & fracture of engineering materials & structures*, ISSN 1460-2695, Jan. 2019, vol. 42, iss. 1, f. 284-294, ilustr. <https://onlinelibrary.wiley.com/doi/epdf/10.1111/ffe.12904>, doi: 10.1111/ffe.12904. [COBISS.SI-ID 16196891]
2. OMAN, Simon, NAGODE, Marko, FAJDIGA, Matija. The material characterization of the air spring bellow sealing layer. *Materials & design*, ISSN 0264-1275, 2009, vol. 30, no. 4, str. 1141-1150.
<http://dx.doi.org/10.1016/j.matdes.2008.06.035>, doi: 10.1016/j.matdes.2008.06.035. [COBISS.SI-ID 10626331],
3. OMAN, Simon, NAGODE, Marko. The influence of piston shape on air-spring fatigue life. *Fatigue & fracture of engineering materials & structures*, ISSN 8756-758X, 2018, vol. 41, iss. 5, str. 1019-1031, ilustr.
<http://onlinelibrary.wiley.com/doi/10.1111/ffe.12748/epdf>, doi: 10.1111/ffe.12748. [COBISS.SI-ID 15773211]
4. OMAN, Simon, NAGODE, Marko. On the influence of the cord angle on air-spring fatigue life. *Engineering failure analysis*, ISSN 1350-6307. [Print ed.], Jan. 2013, vol. 27, str. 61-73, ilustr., doi: 10.1016/j.engfailanal.2012.09.002. [COBISS.SI-ID 12477467]
5. OMAN, Simon, FAJDIGA, Matija, NAGODE, Marko. Estimation of air-spring life based on accelerated experiments. *Materials & design*, ISSN 0264-1275, 2010, vol. 31, iss. 8, str. 3859-3868, doi: 10.1016/j.matdes.2010.03.044. [COBISS.SI-ID 11362075]