

SESTAVLJENA GONILA V MOBILNI TEHNIKI

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	Izbirnost
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Konstruiranje (smer)	2. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code: 0566884

Koda učne enote na članici/UL Member course code: 6031-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: Jernej Klemenc, Marko Nagode, Simon Oman

Izvajalci predavanj:

Izvajalci seminarjev:

Izvajalci vaj:

Izvajalci kliničnih vaj:

Izvajalci drugih oblik:

Izvajalci praktičnega usposabljanja:

Vrsta predmeta/Course Obvezni strokovni predmet na smeri Konstruiranje, ki je

type:

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.

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. Predavanje: Delitev mobilne tehnike:

- Zračna mobilna tehnika;
- Vodna mobilna tehnika;
- Kopenska mobilna tehnika;
- Posebnosti posameznih vrst mobilne tehnike.

2. Predavanje: Uvod v kopensko mobilno tehniko:

- Tirna kolesna vozila – zahtevani pogoji za stabilnost vožnje tirnih vozil;
- Cestna in izven-cestna vozila;
- Gosenična vozila.

3. Predavanje: Bilanca vlečnih sil za vozila s kolesi:

- Kotalni upor;
- Zračni upor;
- Upor strmine;
- Upor priklonika.
- Določitev mejnih vozniških karakteristik z metodo navorov in moči.

4. Predavanje: Večstopenjska zobniška gonila za prilagoditev zunanje karakteristike motorjev z notranjim zgorevanjem izdelani vozniški karakteristiki:

- Osnovna geometrija čelnih zobnikov z ravnimi in poševnimi evolventnim ozobjem;

1. Lecture: Partition of mobile machinery:

- Aircrafts;
- Water vessels;
- Ground vehicles;
- Specialities of different types of mobile machinery.

2. Lecture: Introduction to ground vehicles:

- Railway vehicles – necessary conditions for driving stability of railway vehicles;
- Road- and off-road vehicles;
- Caterpillar vehicle.

3. Lecture: Traction-force balance for wheeled vehicles:

- Rolling resistance;
- Air-drag resistance;
- Inclination resistance;
- Trailer resistance.
- Determination of the limit driving characteristics with the method of torques or power.

4. Lecture: Multi-level gear transmissions for adapting an output characteristics of the internal-combustion engines to the ideal traction characteristic:

<ul style="list-style-type: none"> - Debelina zoba na poljubnem krogu. <p>5. Predavanje: Večstopenjska zobniška gonila za prilagoditev zunanje karakteristike motorjev z notranjim zgorevanjem idelani 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 idelani 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 idelani 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; - Plani stožčasti zobnik; - Sile na ozobju pri stožčastih zobnikih. <p>11. Predavanje: Diferencialno planetno</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.
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<p>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 torno 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. 	<p>10. Lecture: Differential planetary gear with bevel gears:</p> <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. Dinamika vozil - Klemenc, Jernej [COBISS.SI-ID [300796928](#)]
2. Zobniška gonila - Flašker, Jože ; Glodež, Srečko ; Ren, Zoran [COBISS.SI-ID [250895616](#)]
3. Theory of ground vehicles - Wong, Jo Yung [COBISS.SI-ID [1319016](#)]

Cilji in kompetence:

Cilji:

1. Spoznati osnovne principe uravnoveženja 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 vozil.
5. Spoznati principe določevanja mejnih voznih karakteristik kolesnih vozil.

Kompetence:

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.

Objectives and competences:

Objectives:

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.
4. To learn basics of ground-vehicle driving kinematics.
5. To learn principles for assessing the limit driving conditions of ground vehicles.

Competences:

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.

Predvideni študijski rezultati:

Znanja:

Intended learning outcomes:

Knowledge:

<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>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:

<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 namenski didaktični pripomočki (uporaba hibridnega vozila, razvitega na FS). 5. P14: Virtualni eksperimenti. 	<h3>Learning and teaching methods:</h3> <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.

Ocenjevalna lestvica:**Grading system:**

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

1. KOCJAN, Tadej, NAGODE, Marko, **KLEMENC, Jernej**, OMAN, Simon. On fatigue crack growth testing and analysis of non-crystallising rubber using planar tension specimen. Polymer testing. [Print ed.]. Jan. 2023, vol. 117, str. 1-10, ilustr. ISSN 0142-9418. <https://www.sciencedirect.com/science/article/pii/S0142941822003403>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=142405>, DOI: 10.1016/j.polymertesting.2022.107819. [COBISS.SI-ID [128185859](#)].
2. GOSAR, Aleš, EMRI, Igor, **KLEMENC, Jernej**, NAGODE, Marko, OMAN, Simon. On the vibration-damping properties of the prestressed polyurethane granular material. Polymers. 2023, vol. 15, iss. 5, str. 1-22, ilustr. ISSN 2073-4360. <https://www.mdpi.com/2073-4360/15/5/1299>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=144812>, DOI: 10.3390/polym15051299. [COBISS.SI-ID [145104131](#)].
3. PANIĆ, Branislav, NAGODE, Marko, **KLEMENC, Jernej**, OMAN, Simon. On methods for merging mixture model components suitable for unsupervised image segmentation tasks. Mathematics. Nov. 2022, vol. 10, iss. 22, str. 1-22, ilustr. ISSN 2227-7390. <https://www.mdpi.com/2227-7390/10/22/4301>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=142662>, DOI: 10.3390/math10224301. [COBISS.SI-ID [129898499](#)]
4. NEČEMER, Branko, **KLEMENC, Jernej**, GLODEŽ, Srečko. The computational LCF-analyses of chiral and Re-entrant auxetic structure using the direct cyclic algorithm. Materials Science & Engineering. A, Structural materials: Properties, Microstructure and Processing. [Print ed.]. July 2020, vol. 789 (139618), str. 1-9. ISSN 0921-5093. DOI: 10.1016/j.msea.2020.139618. [COBISS.SI-ID [19638019](#)].
5. OKORN, Ivan, NAGODE, Marko, **KLEMENC, Jernej**. Operating performance of external non-involute spur and helical gears : a review. Strojniški vestnik. May 2021, vol. 67, no. 5, str. 256-271, si 34, ilustr. ISSN 0039-2480.

<https://www.sv-jme.eu/sl/article/operating-performance-of-non-involute-spur-and-helical-gears-a-review/>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=127401>, <http://www.dlib.si/details/URN:NBN:SI:doc-0VNIJTUM>, DOI: 10.5545/sv-jme.2020.7094. [COBISS.SI-ID [65853443](#)].

Marko Nagode:

1. KOCJAN, Tadej, **NAGODE, Marko**, KLEMENC, Jernej, OMAN, Simon. Prediction of actual fatigue test temperature and isothermal fatigue life curves for non-crystallising rubber under fully relaxing uni-axial loading conditions. International journal of fatigue. Apr. 2022, vol. 157, str. 1-13, ilustr. ISSN 0142-1123.
<https://www.sciencedirect.com/science/article/pii/S0142112321004679>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=141044>, DOI: 10.1016/j.ijfatigue.2021.06622. [COBISS.SI-ID [92807171](#)]
2. **NAGODE, Marko**, GOSAR, Aleš, SWEENEY, Caoimhe A., JAGUEMONT, Joris, MIERLO, Joeri Van, ŠERUGA, Domen. Mechanistic modelling of cyclic voltage-capacity response for lithium-ion batteries. Energy. Nov. 2019, vol. 186, str. 1-12, ilustr. ISSN 0360-544
<https://www.sciencedirect.com/science/article/pii/S036054421931463X?via%3Dihub#!>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=109433>, DOI: 10.1016/j.energy.2019.07.121. [COBISS.SI-ID [16771099](#)]
3. BEŠTER, Tomaž, OMAN, Simon, **NAGODE, Marko**. Determining influential factors for an air spring fatigue life. Fatigue & fracture of engineering materials & structures. Jan. 2019, vol. 42, iss. 1, f. 284-294, ilustr. ISSN 1460-2695. <https://onlinelibrary.wiley.com/doi/epdf/10.1111/ffe.12904>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=105271>, DOI: 10.1111/ffe.12904. [COBISS.SI-ID [16196891](#)]
4. PEČNIK, Matija, **NAGODE, Marko**, ŠERUGA, Domen. Influence of geometry and safety factor on fatigue damage predictions of a cantilever beam. Structural engineering and mechanics. Apr. 2019, vol. 70, no. 1, str. 33-41, ilustr. ISSN 1225-4568. <http://www.techno-press.org/download.php?journal=sem&volume=70&num=1&ordernum=3>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=107393>, DOI: 10.12989/sem.2019.70.1.033. [COBISS.SI-ID [16558875](#)]
5. OMAN, Simon, **NAGODE, Marko**. The influence of piston shape on air-spring fatigue life. Fatigue & fracture of engineering materials & structures. 2018, vol. 41, iss. 5, str. 1019-1031, ilustr. ISSN 8756-758X. <http://onlinelibrary.wiley.com/doi/10.1111/ffe.12748/epdf>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=105272>, DOI: 10.1111/ffe.12748. [COBISS.SI-ID [15773211](#)]

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. 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](#)]

3. **OMAN, Simon**, NAGODE, Marko, KLEMENC, Jernej, MAJDIČ, Franc, HOČEVAR, Marko, GOSAR, Aleš, ŠKRLEC, Andrej, OLAH, Laslo. Submersible pump assembly and method for use of same : United States patent US 10,995,745 B1, 2021-05-04. Alexandria: United States Patent and Trademark Office, 2021. 10 f., ilustr. [COBISS.SI-ID [63338755](#)]
4. **OMAN, Simon**, NAGODE, Marko. Center crush BWP30 : support plate design modification to change its material to PA-GF composite. Ljubljana: Faculty of Mechanical Engineering, LASEM, 2022. 17 f., graf. prikazi. [COBISS.SI-ID [124489987](#)]
5. GOSAR, Aleš, EMRI, Igor, KLEMENC, Jernej, NAGODE, Marko, **OMAN, Simon**. On the vibration-damping properties of the prestressed polyurethane granular material. *Polymers*. 2023, vol. 15, iss. 5, str. 1-22, ilustr. ISSN 2073-4360. <https://www.mdpi.com/2073-4360/15/5/1299>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=144812>, DOI: 10.3390/polym15051299. [COBISS.SI-ID [145104131](#)]