

NUMERIČNO MODELIRANJE SKLOPLJENIH SISTEMOV

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	NUMERIČNO MODELIRANJE SKLOPLJENIH SISTEMOV
Course title:	NUMERICAL MODELLING OF COUPLED SYSTEMS
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo, tretja stopnja, doktorski	Ni členitve (študijski program)		Celoletni	izbirni

Univerzitetna koda predmeta/University course code:

0033420

Koda učne enote na članici/UL Member course code:

7012

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorials	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individual student work	ECTS
90					160	10

Nosilec predmeta/Lecturer:

Božidar Šarler, Nikolaj Mole

Izvajalci predavanj:

Nikolaj Mole, Božidar Šarler

Izvajalci seminarjev:

Izvajalci vaj:

Izvajalci kliničnih vaj:

Izvajalci drugih oblik:

Izvajalci praktičnega usposabljanja:

Vrsta predmeta/Course type:

Izbirni predmet /Elective course

Jeziki/Languages:

Predavanja/Lectures:

Angleščina, Slovenščina

Vaje/Tutorial:

Angleščina, Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:**Prerequisites:**

Veljajo splošni pogoji za doktorski študij.

General prerequisites for the third level studies.

Vsebina:**Content (Syllabus outline):**

- Uvod v multifizikalne probleme: Problematika analize tehniških sestavov iz različnih gradiv ali medijev z vidika sočasnosti različnih fizikalnih pojavov. Identifikacija prostorskih podobmočij, časovnih domen ter fizikalnih pojavov, določitev medsebojnega vpliva. Klasifikacija problemov na multifizikalne in večobmočne probleme. Primeri sklopljenih problemov iz področij mehanike kontinuuma, mehanike fluidov, prevoda toplote in elektromagnetizma.
- Matematični modeli in njihove lastnosti: Vodilne enačbe posameznih fizikalnih pojavov in njihove lastnosti. Enobmočni in večobmočni problemi, multifizikalni problemi. Robni pogoji in pogoji fizikalno konsistentnega prehoda, karakterizacija soodvisnosti med veličinami fizikalno sklopljenih sistemov. Pristopi k modeliranju multifizikalnih problemov glede na stopnjo sklopljenosti, nelinearnost v odzivu ter časovno soodvisnost. Izbor modela v odnosu na cilj in kriterij, validacija modela.
- Numerično reševanje: Izbira primerne numerične metode (MKR, MKE, MRE, MKV) glede na izkazano naravo problema. Prostorska in časovna diskretizacija iz vidika medsebojne povezanosti, strategije numeričnega

- Introduction to multiphysic problems: On the analysis of technical systems composed from different materials or media considering simultaneous interaction between different physical phenomena. Identification of space subdomains, time scales and physical phenomena; determination of their mutual influence. Classification of problems to multiphysics and multidomain problems. Examples of coupled problems from the fields of continuum mechanics, fluid mechanics, heat transfer and electromagnetism.
- Mathematical models and their properties: Governing equations of several physical problems and their properties. One-domain and multidomain problems, multiphysics problems. Boundary conditions and interface conditions, characterization of interdependence between physical variables of coupled systems. Approaches to modelling of multiphysics problems regarding degree of coupling, nonlinearity of response and time simultaneity. About choosing an adequate model regarding the prescribed analysis criteria; validation of the model.
- Advanced numerical solution methods: On the choice of adequate numerical method (FEM, FDM, BEM,

<p>reševanja časovne integracije glede na stopnjo sklopljenosti in nelinearnosti. Računalniške simulacije problemov iz vidika časovne potratnosti in eventualne poenostavitve numeričnih modelov. Paralelno reševanje in sinhronizacija. Uporaba sodobnih računalniških tehnologij in programov.</p> <ul style="list-style-type: none"> • Simuliranje tehnoloških procesov: Obravnava primerov mehanske interakcije med sistemi (kontakt med deformabilnimi telesi, interakcija med trdnino in fluidom) in fizikalne sklopljenosti (elektromagnetizem, prevod toplote, mehanika). Simuliranje procesov plastičnega preoblikovanja, procesov kontinuiranega litja z valjanjem, varjenja, induktivnega segrevanja, toplotnih obdelav, ... 	<p>FVM) regarding nature of the problem. Space and time discretization in a view of their mutual interaction; strategies used for time integration regarding the degree of physical coupling and problem nonlinearity. Computer simulations of problems in view of time consumption and possible simplifications of numerical models. Parallel computations and computational process synchronization. Modern computation technologies and programs.</p> <ul style="list-style-type: none"> • Simulations of manufacturing processes: Analyses of mechanical interactions between systems (contact between deformable bodies, fluid-structure interactions) and analyses of physical coupling (electromagnetism, heat transfer, mechanical deformation) occur. Case studies: simulation of processes of metal forming, continuous casting and rolling, welding, inductive heating, heat treatment...
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Temeljna literatura in viri/Readings:

- [1] M.C.S. Arriaga, J. Bundschuh, F.J.Dominguez-Mota: Numerical modelling of coupled phenomena in science and engineering (Multiphysics modeling), Routledge, Taylor & Francis, 2008.
- [2] B.J. Zimmerman: Multiphysics modelling with finite element methods, World Scientific Publishing Co. Pte. Ltd., 2006.
- [3] S.K. Chakrabarti (Editor): Numerical Models in Fluid-Structure Interaction, Advances in Fluid Mechanics, WIT press, 2007.
- [4] A. J. KASSAB, M. H. ALIABADI (Editors), Coupled Field Problems, Advances in Boundary Elements, WIT press, 2001.
- [5] Radaj D.: Heat Effects of Welding. Temperature Field, Residual Stress, Distortion; Springer-Verlag, Heidelberg, 1992.

Cilji in kompetence:

Cilji:

Kot osnovni cilj gre jemati zavedanje o fizikalni sklopljenosti v večini tehniških sistemov ter stopnji sklopljenosti, ki posledično bolj ali manj vpliva na posamični fizikalni odziv. Ob ustreznem razumevanju posamičnih fizikalnih mehanizmov in njihove medsebojne

Objectives and competences:

Goals:

The principal message of the course is to become aware of physical coupling in most of the technical systems and of the degree of coupling, which affects more or less the individual physical phenomenon response. By acquiring proper understanding of several physical

<p>interakcije je cilj študenta usposobiti za najzahtevnejše razvojno usmerjene analize na področju kompleksnih konstrukcijskih sestavov ter izdelovalnih tehnologij.</p> <p>Kompetence:</p> <p>Študent osvoji razumevanje dejavnikov, ki opredeljujejo odziv v tehniških sistemih zaznamovanih z več fizikalnimi pojavi hkrati. Na tej osnovi se bo znal odločiti, kako pristopiti k analizi delovanja heterogenih mehanskih sestavov in k analizi vrste tehnoloških postopkov. Znal bo postaviti fizikalno objektivne numerične modele, na osnovi katerih bo s sofisticiranimi računskimi orodji lahko kompetentno zasledoval učinke predpostavljenih vhodnih parametrov.</p>	<p>mechanisms and their mutual interaction it is the aim to qualify student for pretentious development analyses in the field of complex physical systems and manufacturing technologies.</p> <p>Competences:</p> <p>Student acquires the understanding of factors that determine response of technical systems with several physical phenomena interacting simultaneously. With that knowledge, student will know how to properly approach to the analysis of heterogeneous mechanical systems as well as to the analysis of different kind of technological processes. Student will also acquire knowledge on how to prepare physically objective numerical models, which can be used subsequently, with a support of well developed computer softwares provided, to asses competently the effects of prescribed input parameters by simulation.</p>
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<p>Predvideni študijski rezultati:</p> <p>Študent osvoji razumevanje dejavnikov, ki opredeljujejo odziv v tehniških sistemih zaznamovanih z več fizikalnimi pojavi hkrati. Na tej osnovi se bo znal odločiti, kako pristopiti k analizi delovanja heterogenih mehanskih sestavov in k analizi vrste tehnoloških postopkov. Znal bo postaviti fizikalno objektivne numerične modele, na osnovi katerih bo s sofisticiranimi računskimi orodji lahko kompetentno zasledoval učinke predpostavljenih vhodnih parametrov.</p>	<p>Intended learning outcomes:</p> <p>Student acquires the understanding of factors that determine response of technical systems with several physical phenomena interacting simultaneously. With that knowledge, student will know how to properly approach to the analysis of heterogeneous mechanical systems as well as to the analysis of different kind of technological processes. Student will also acquire knowledge on how to prepare physically objective numerical models, which can be used subsequently, with a support of well developed computer softwares provided, to asses competently the effects of prescribed input parameters by simulation.</p>
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<p>Metode poučevanja in učenja:</p> <p>Predavanja, laboratorijske vaje, seminarsko delo, e-izobraževanje, konzultacije. Seminarsko delo v čim večji</p>	<p>Learning and teaching methods:</p> <p>Lectures, laboratory practice & seminar work, e-education, consulting. The seminar work is related, as much as</p>
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meri navezujoče se na področje doktorskega raziskovanja. Študij z uporabo priporočene literature.	possible, to the student's doctoral research field. Study on a recommended literature basis.
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Načini ocenjevanja:	Delež/ Weight	Assessment:
Ustni izpit, poročilo o seminarskem delu. Pogoji za opravljanje ustnega izpita je uspešno izdelano in pozitivno ocenjeno seminarsko delo. • projekt (seminarsko delo) (70%) • ustno izpraševanje (30%) Oral exam, report on seminar work. The condition for admission to oral exam is successful completion of seminar work, rewarded with a passing grade. • project (seminar work) (70%) • oral examination (30%)		Oral exam, report on seminar work. The condition for admission to oral exam is successful completion of seminar work, rewarded with a passing grade. • project (seminar work) (70%) • oral examination (30%)

Reference nosilca/Lecturer's references:

doc.dr. Nikolaj MOLE

BOBOVNIK, Gregor, MOLE, Nikolaj, KUTIN, Jože, ŠTOK, Boris, BAJSIČ, Ivan. Coupled finite-volume/finite-element modelling of the straight-tube Coriolis flowmeter. *J. of Fluids and Structures*, 2005.

MOLE, Nikolaj, BOBOVNIK, Gregor, KUTIN, Jože, ŠTOK, Boris, BAJSIČ, Ivan. An Improved Three-Dimensional Coupled Fluid-Structure Model for Coriolis Flowmeters. *J. of Fluids and Structures*, 2008.

BOBOVNIK, Gregor, KUTIN, Jože, MOLE, Nikolaj, ŠTOK, Boris, BAJSIČ, Ivan. Numerical analysis of installation effects in coriolis flowmeters : a case study of a short straight tube full-bore design. *Flow measurement and instrumentation*, 2013.

BOBOVNIK, Gregor, KUTIN, Jože, MOLE, Nikolaj, ŠTOK, Boris, BAJSIČ, Ivan. Numerical analysis of installation effects in Coriolis flowmeters : single and twin tube configurations. *Flow measurement and instrumentation*, 2015.

BOJINOVIĆ, Marko, MOLE, Nikolaj, ŠTOK, Boris. A computer simulation study of the effects of temperature change rate on austenite kinetics in laser hardening. *Surface & coatings technology*, 2015.

prof. dr. Božidar ŠARLER

KOVAČIČ, Miha, ŠARLER, Božidar. Genetic programming prediction of the natural gas consumption in a steel plant. *Energy*, ISSN 0360-5442. [Print ed.], 2014, vol. 66, str. 273-284, doi: 10.1016/j.energy.2014.02.001. [COBISS.SI-ID 3219707], [JCR, SNIP, WoS do 22. 1. 2017: št. citatov (TC): 15, čistih citatov (CI): 12, čistih citatov

na avtorja (CIAu): 6.00, Scopus do 27. 1. 2017: št. citatov (TC): 17, čistih citatov (CI): 14, čistih citatov na avtorja (CIAu): 7.00] kategorija: 1A1 (Z, A'', A', A1/2); uvrstitev: SCI, Scopus, MBP; tipologijo je verificiral OSICT

LIU, Qingguo, ŠARLER, Božidar. A non-singular method of fundamental solutions for two-dimensional steady-state isotropic thermoelasticity problems. Engineering analysis with boundary elements, ISSN 0955-7997. [Print ed.], Feb. 2017, vol. 75, str. 89-102, ilustr., doi: 10.1016/j.enganabound.2016.11.010. [COBISS.SI-ID 4619259], [JCR, SNIP, WoS do 24. 2. 2017: št. citatov (TC): 0, čistih citatov (CI): 0, čistih citatov na avtorja (CIAu): 0, Scopus do 13. 1. 2017: št. citatov (TC): 0, čistih citatov (CI): 0, čistih citatov na avtorja (CIAu): 0]

MAVRIČ, Boštjan, ŠARLER, Božidar. Local radial basis function collocation method for linear thermoelasticity in two dimensions. V: ŠARLER, Božidar (ur.). Third International Conference on Computational Methods for Thermal Problems (ThermaComp 2014), Lake Bled, Slovenia, 2-4 June 2014, (International Journal of Numerical Methods for Heat & Fluid Flow, ISSN 0961-5539, vol. 25, iss. 6, vol. 26, iss. 2). Bradford: Emerald, 2015-2016, vol. 25, no. 6, str. 1488-1510, ilustr., doi: 10.1108/HFF-11-2014-0359. [COBISS.SI-ID 3976187], [JCR, SNIP, WoS do 26. 2. 2017: št. citatov (TC): 4, čistih citatov (CI): 0, čistih citatov na avtorja (CIAu): 0, Scopus do 28. 2. 2017: št. citatov (TC): 4, čistih citatov (CI): 1, čistih citatov na avtorja (CIAu): 0.50] tipologija 1.08 -> 1.01, kategorija: 1A2 (Z, A1/2); uvrstitev: SCI, Scopus, MBP; tipologijo je verificiral OSICN

KOŠNIK, Nejc, LORBIECKA, Agnieszka Zuzanna, MAVRIČ, Boštjan, ŠARLER, Božidar. A multiphysics and multiscale model for low frequency electromagnetic direct-chill casting. Journal of physics, Conference series, ISSN 1742-6588. [Print ed.], ilustr. <http://iopscience.iop.org/article/10.1088/1757-899X/117/1/012052/pdf>, doi: 10.1088/1757-899X/117/1/012052. [COBISS.SI-ID 1199274], [SNIP, Scopus do 1. 3. 2017: št. citatov (TC): 1, čistih citatov (CI): 1, čistih citatov na avtorja (CIAu): 0.25]

HANOGLU, Umut, ŠARLER, Božidar. Simulation of hot shape rolling of steel in continuous rolling mill by local radial basis function collocation method. Computer modeling in engineering & sciences, ISSN 1526-1492. Tiskana izd., 2015, vol. 109, no. 5, str. 447-479, ilustr. <http://www.techscience.com/doi/10.3970/cmesc.2015.109.447.html>. [COBISS.SI-ID 1199018], [JCR, SNIP, WoS do 26. 2. 2017: št. citatov (TC): 1, čistih citatov (CI): 0, čistih citatov na avtorja (CIAu): 0, Scopus do 28. 1. 2017: št. citatov (TC): 1, čistih citatov (CI): 0, čistih citatov na avtorja (CIAu): 0] kategorija: 1A3 (Z); uvrstitev: SCI, Scopus, MBP; tipologijo je verificiral OSICT

LORBIECKA, Agnieszka Zuzanna, ŠARLER, Božidar. Simulation of dendritic growth with different orientation by using the point automata method. Computers, materials & continua, ISSN 1546-2218, 2010, vol. 18, no. 1, str. 69-103. [COBISS.SI-ID 1729275], [JCR, SNIP, WoS do 20. 4. 2017: št. citatov (TC): 17, čistih citatov (CI): 6, čistih citatov na avtorja (CIAu): 3.00, Scopus do 23. 4. 2017: št. citatov (TC): 23, čistih citatov (CI): 8, čistih citatov na avtorja (CIAu): 4.00] kategorija: 1A1 (Z, A', A1/2); uvrstitev: SCI, Scopus, MBP; tipologijo je verificiral OSICN

VERTNIK, Robert, ŠARLER, Božidar. Simulation of continuous casting of steel by a meshless technique. International journal of cast metals research, ISSN 1364-0461, 2009, vol. 22, no. 1/4, str. 311-313. [COBISS.SI-ID 1165819], [JCR, SNIP, WoS do 20. 4. 2017: št. citatov (TC): 24, čistih citatov (CI): 14, čistih citatov na avtorja

(CIAu): 7.00, Scopus do 22. 2. 2017: št. citatov (TC): 30, čistih citatov (CI): 18, čistih citatov na avtorja (CIAu): 9.00]kategorija: 1A3 (Z); uvrstitev: SCI, Scopus, MBP; tipologijo je verificiral OSICT

LORBIECKA, Agnieszka Zuzanna, VERTNIK, Robert, GJERKEŠ, Henrik, MANOJLOVIČ, Gojko, SENČIČ, Bojan, CESAR, Janko, ŠARLER, Božidar. Numerical modeling of grain structure in continuous casting of steel. Computers, materials & continua, ISSN 1546-2218, 2009, vol. 8, no. 3, str. 195-208, ilustr., doi: 10.3970/cmc.2008.008.195. [COBISS.SI-ID 1080315], [JCR, SNIP, WoS do 19. 3. 2017: št. citatov (TC): 1, čistih citatov (CI): 0, čistih citatov na avtorja (CIAu): 0, Scopus do 8. 5. 2016: št. citatov (TC): 16, čistih citatov (CI): 3, čistih citatov na avtorja (CIAu): 0.43]kategorija: 1A1 (Z, A', A1/2); uvrstitev: SCI, Scopus, MBP; tipologijo je verificiral OSICT